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Resource Guide for Heavy-Duty LNG Vehicles, Infrastructure, and Support Operations

FINAL REPORT

March, 2002

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This Guide is designed to assist decision makers and fleet managers, in considering the use of liquefied natural gas (LNG) in heavy-duty vehicles. The objective of the Guide is to answer questions regarding implementation of LNG fuel in the fleet, e.g., getting started, likely costs, benefits, and lessons others have learned. This Guide also provides you with contact information for representatives of companies now using these fuels, manufacturers and suppliers of the fuels, and technical and governmental reference materials. The information in the Guide is intended to be useful for both new and existing end-users of heavy-duty LNG vehicles, so that operations can be initiated or conducted in a cost-effective manner with minimal disruptions related to the new fuel technology.

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Abbreviation List

A&E—Architecture and Engineering
AFDC—Alternative Fuel Data Center
AFV—Alternative fuel vehicle
AMFA—Alternative Motor Fuels Act of 1998
ANL—Argonne National Laboratory
APTA—American Public Transportation Association
ASME—American Society of Mechanical Engineers
BNL—Brookhaven National Laboratory
BTS—Bureau of Transportation Statistics
BTU—British Thermal Units
C—Celsius
CAAA—Clean Air Act Amendments of 1990
CARB—California Air Resources Board
CEC—California Energy Commission
CMAQ—congestion mitigation and air quality
CNG—compressed natural gas
CO—carbon monoxide
CO_2—carbon dioxide
DOE—U.S. Department of Energy
DOT—U.S. Department of Transportation
DPF—diesel particulate filter
EIA—Energy Information Administration
EPA—U.S. Environmental Protection Agency
EPAct—Energy Policy Act of 1992
F—Fahrenheit
Gal—gallon
GAO—General Accounting Office
GGE—gasoline gallon equivalent
GHG—greenhouse gases
GREET—Greenhouse Gases, Regulated Emissions, and Energy use in Transportation
GRI—Gas Research Institute
GTI—Gas Technology Institute
GTL—gas-to-liquid process
H_2—hydrogen
HC—hydrocarbons
HHV—higher heating value
IC—internal combustion
ICTC—Interstate Clean Transportation Corridor
IGT—Institute of Gas Technology
ILEV—inherently low emission vehicle
IPCC—Intergovernmental Panel on Climate Change
ISTEA—Intermodal Surface Transportation Efficiency Act of 1991
kg—kilogram
kPa—kiloPascal

LCNG—liquefied to compressed natural gas
LEV—low emission vehicle
LFL—lower flammability limit
LHV—lower heating value
LNG—liquefied natural gas
LPG—liquefied petroleum gas (i.e., propane)
MMcf—million cubic feet (i.e., of gas burned)
MPa—megaPascals
MSDS—material safety data sheets
NCSL—National Council of State Legislatures
NFPA—National Fire Protection Association
NGV—natural gas vehicle
NGVC—Natural Gas Vehicle Coalition
NMHC—non-methane hydrocarbons
NO_x—oxides of nitrogen
NRU—nitrogen rejection units
NREL—National Renewable Energy Laboratory
OEM—original equipment manufacturer
OTT—DOE's Office of Transportation Technologies
OHVT—DOE's Office of Heavy Duty Vehicles
ORNL—Oak Ridge National Laboratory
PM—particulate matter (i.e., soot)
PMI—preventive maintenance inspection
Ppm—parts per million
Psi—pounds per square inch
Psig—pounds per square inch (gauge)
RLM—refrigerated liquid methane
SAE—Society of Automotive Engineers
Scf—standard cubic feet
SOP—standard operating procedure
SULEV—super ultra low emission vehicle
TAC—toxic air contaminant
TEA-21—Transportation Equity Act for the 21st Century (issued 1998)
THC—total hydrocarbons
ULEV—ultra low emission vehicle
ULSD—ultra-low sulfur diesel

Introduction

This publication, entitled *Resource Guide for Heavy-Duty LNG Vehicles, Infrastructure, and Support Operations,* is designed to assist the decision maker and/or fleet manager, in considering the use of liquefied natural gas (LNG) in heavy-duty vehicles. The objective of the guide is to answer questions regarding implementation of LNG fuel in the fleet, e.g., getting started, likely costs, benefits, and lessons learned. This guide also provides contact information for representatives of companies now using these fuels, manufacturers and suppliers of the fuels and supporting equipment, and technical and governmental reference materials. The information in the guide is intended to be useful for both new and existing end-users of heavy-duty LNG vehicles, so that operations can be initiated or conducted in a cost-effective manner with minimal disruptions related to the new fuel technology.

This guide is unlike other publications and Internet sites concerning alternative fuels. These sources concentrate on selection of alternative fuels, development of fueling station equipment, or procedures to apply for available funding. The unique feature of this guide is that after providing brief background information concerning alternative fuels, it focuses on LNG and provides implementation guidance for the decision maker, fleet manager, or end-user. This includes planning and handling issues that can occur before and during purchase decisions, after the point of sale of equipment or acceptance of funding, and after the vehicles are on the road. However, this guide is not intended to advocate the use of LNG over other possible alternative fuels (see more details in the chapter titled **Why Alternative Fuels?**). For those fleet managers who have already decided to consider using LNG, this *Resource Guide* will help to anticipate the issues and navigate the maze to the selection of fuel, successful installation of infrastructure, and deployment of LNG-fueled vehicles in the fleet.

Organization of Resource Guide

The *Resource Guide* is divided into three sections: ***Section 1−The Basics***, ***Section 2−The Science and Details***, and ***Section 3−The Appendix***. For easy cross-referencing, topics in sections 1 and 2 have the same top-level headings.

- ***The Basics*** section is aimed at the decision makers and provides summaries of the information needed to make the decisions and referrals are made to greater detail on each subject in Section 2, if desired.

- ***The Science and Details*** section is focused on the information and support needs of fleet managers and personnel. This section covers the same subjects as ***The Basics*** but provides historical background concerning LNG, information regarding the fuel's performance, expanded detail, lessons learned, technical discussions and references, contacts for suppliers, references to individuals and Web sites, actions to avoid, and "how-to's."

- ***The Appendix*** section contains a listing of technical documents, technical papers reporting on a variety of LNG fleet experiences, issues, standards, federal and state regulations, and safety assessments; LNG-related periodicals; web sites; and fleets currently using LNG.

Section 1 – The Basics	***Section 2 – The Science and Details***	***Section 3 – The Appendix***
- Why Alternative Fuels? - What Is LNG? - How Do We Get Started? - How Do We Resolve LNG Problems? - What Are the Safety Considerations For LNG Vehicle Operations? - Is LNG Readily Available? - What Will This Cost Me? - Where Can I Find More Answers?	Topics in this section are the same as in Section 1 but covered in more detail.	- Related Documents - LNG-Related Periodicals - Helpful Web Sites - LNG Fleets

This guide is a joint effort between the U.S. Department of Energy's (DOE) Brookhaven National Laboratory (BNL) and the Gas Technology Institute (GTI). BNL is a DOE national laboratory, which conducts basic and applied research in the physical, biomedical, and environmental sciences as well as in selected energy technologies. The guide is supported through DOE's Office of Heavy Vehicle Technologies. GTI is the combined company that joins the resources and strong technological heritage of the Gas Research Institute (GRI) and the Institute of Gas Technology (IGT). GTI is a problem-solving organization focused on developing practical technologies and solutions for natural gas producers, refiners, chemical facilities, pipelines, and a wide range of natural gas users, including utilities and industrial clients.

Web Site References:
Gas Technology Institute: www.gastechnology.org
Brookhaven National Laboratory: www.bnl.gov
U.S. Department of Energy, Office of Transportation Technologies: www.ott.doe.gov
Natural Gas Vehicle Coalition: www.ngvc.com

Finally, this *Resource Guide* is intended to be a useful tool, but is only a starting point for information on using LNG. This report provides resources available via personal contacts, the Internet, accessible reports, companies now using LNG, and information from those who have experienced start-up.

SECTION 1

THE BASICS

Topic, Page

What's In This Section?

This section provides a brief summary of the major topics listed in the box above and is intended to be most useful to company decision makers and key personnel. Section 2 contains additional details and is designed to assist fleet personnel in implementing the program.

Why Alternative Fuels?

Alternative vehicle fuels have been available as long as gasoline and diesel fuels. Two alternative fuels—natural gas and electricity—have been used for vehicle propulsion since the first automobiles became available, but gasoline and diesel fuels quickly became the fuels of choice nearly 100 years ago. Today, transportation vehicles use 68% of all petroleum consumed

Over the past 12 years, the return to alternative fuels has been accelerating because of environmental and energy security concerns.

The definition of alternative fuels may vary slightly depending on the state in which the vehicle is used. In general, alternative vehicle fuels in use today include natural gas (compressed and liquefied), alcohol fuels (ethanol and methanol), propane, electricity, cleaner burning diesel (e.g., biodiesel, natural gas-derived diesel fuel – Fischer-Tropsch diesel), and, most recently, hydrogen for fuel cells. Blends of these fuels with gasoline or diesel fuel, as well as with other chemicals, may also be considered part of the alternative fuels group. These fuels are currently powering a variety of vehicles, including heavy-duty trucks, garbage packers and dump trucks, snowplows, package delivery vans, buses, taxicabs, and passenger cars.

Government regulations to reduce air pollution and public concerns regarding harmful emissions from transportation vehicles are the major reasons why the use of alternative vehicle fuels is increasing. Using alternative fuels in transportation vehicles can reduce air pollution and reduce the nation's dependence on foreign oil, because most of the alternative fuels are plentiful in the U.S.

Provisions of the Alternative Motor Fuels Act of 1988 (AMFA), the Clean Air Act Amendments of 1990 (CAAA), the Energy Policy Act of 1992 (EPAct), and other federal and state legislation require a gradual transition for some fleets from fossil fuels, such as gasoline or diesel, to alternative fuels. These regulations also include requirements for monitoring emissions and providing incentives to potential users of alternative fuel vehicles. Two federal agencies, the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE), have enabled and promoted the movement to alternative fuel vehicles. Many states have regulations and incentive programs to increase the use of alternative vehicle fuels. The result is that emission regulations are expected to be much stricter beginning in 2007.

Natural gas is a clean-burning alternative transportation fuel available in adequate quantities today—producing significantly lower emissions than required by the Clean Air Act Amendments of 1990. Natural gas vehicles (NGVs) have been certified to perform in compliance with all current environmental emission standards, including standards limiting particulate matter, carbon monoxide, and oxides of nitrogen. Figure 1-1 shows an LNG bus from Orange County Transportation Authority in Orange, California.

Figure 1-1. LNG Bus at OCTA in Orange, California

A side benefit of the pressures to convert U.S. fleets of light- or heavy-duty vehicles to alternative fuels is that manufacturers have found ways to reduce exhaust emissions from conventional vehicles (i.e., gasoline and diesel powered) over the past l5 years. The downside of this aspect is that, despite the legislation and incentives, consumption of petroleum-based fuels continues to increase, further entrenching our dependence on foreign oil. The purchase of alternative fuel vehicles has increased significantly, but few of the light- and medium-duty alternative fuel vehicles purchased are dedicated vehicles. Dedicated vehicles can only operate on the alternative fuel that they were designed for. Most of the medium- and light-duty alternative vehicles are bi-fuel (operates on the alternative fuel or conventional fuel) or dual-fuel (can use an alternative fuel, conventional fuel, or some combination). Surveys indicate that most bi-fuel and duel-fuel vehicles are operating almost exclusively on gasoline or diesel because of the lack of alternative fuel filling stations.

To encourage the use of alternative fuels, governmental agencies and other sources offer incentives to vehicle manufacturers, sales outlets, and buyers to promote the use of alternative fuels. Current and potential future incentive programs are described on the following Web sites:

- Alternative Fuel Data Center: www.afdc.doe.gov
- Clean Cities: www.ccities.doe.gov
- Natural Gas Vehicle Coalition: www.ngvc.org

Once a company has decided to use an alternative fuel in the fleet, the first executive decision to make is the selection of the alternative fuel best suited for your company's operation. Each of the alternative fuels mentioned earlier has positive points and potential downsides. The major variables among the alternative fuels are (1) the security of the fuel supply and proximity of the fuel supplier, (2) the availability of on-site space for installing the fuel supply facility or access to a public fuel supply facility, (3) potential complications of retrofitting the engines or purchasing new vehicles, (4) training required for drivers, maintenance and fueling personnel, (5) possible incentives, grants, or rebates from federal or state funds or vehicle manufacturers, and (6) the estimated costs of all of these factors. This *Resource Guide* assumes that you have thought through these variables and decided to more thoroughly consider the use of LNG in your fleet.

What Is LNG?

Liquefied natural gas (LNG) is the liquid form of natural gas. LNG is essentially the same as the natural gas used to heat homes, commercial buildings, and plants. Natural gas is composed primarily of methane, with smaller amounts of other hydrocarbons such as ethane, propane, butane, pentane, and gases such as nitrogen and carbon dioxide. Natural gas, with an octane rating of 130, is well suited for spark-ignited internal combustion engines, but is not as well suited for compression ignition cycle engines (diesel engines) without some assistance in starting the combustion process such as using a small amount of diesel fuel (dual-fuel engines) or adding spark plugs.

The process of liquefying gases was invented in the early 1900's to separate components of atmospheric gases by cooling air in stages under pressure until the constituents (e.g., oxygen, nitrogen) condensed to a liquid form. Today, LNG is purified before liquefaction, i.e., elements in pipeline gas (such as condensable water, carbon dioxide, and odorants) are removed. Then, refrigeration at cryogenic temperatures and/or depressurization is used to liquefy the natural gas. This process removes some of the heavier hydrocarbons, leaving mostly methane (85 to 99 percent). The resulting LNG is a clear and odorless cryogenic liquid that is non-toxic, non-corrosive, and non-carcinogenic. Most LNG is produced at storage locations operated by natural gas suppliers and at cryogenic extraction plants in gas-producing states.

Compressed natural gas (CNG), like LNG, is the same fuel used for home heating and cooking. CNG is different from LNG in that it is a gas that is compressed to nominal pressures as high as 3,600 pounds per square inch (psi). (Pressures can be even higher when taking temperature compensation effects into account.) As noted earlier, this Guide is not advocating the use of LNG over any other alternative fuel such as CNG. The decision between LNG and CNG, for example, is usually determined by comparing the space needed for fueling infrastructure, the availability of the fuel and the vehicles, the energy density of the two fuels, weight of the vehicle fuel tanks, fuel cost, and range allowed by the on-board fuel supply.

LNG has a lower energy density than gasoline and diesel, but a higher energy density than CNG and many other alternative fuels. This means that LNG has less energy per volume than gasoline or diesel fuels. (There is a 1.55 to 1 energy ratio when gasoline is compared to LNG and a 1.67 to 1 energy ratio when diesel is compared to LNG).

Liquefied to compressed natural gas (LCNG) is produced by pumping LNG up to a selected pressure level and then vaporizing the liquid through a heat exchanger (vaporizer). It is more efficient and faster to pressurize natural gas in liquid form. LCNG can be pressurized via a

relatively small cryogenic pump (e.g., basketball size). LCNG can be used for light- and heavy-duty vehicles and its fueling stations and operations are similar to those for LNG.
Although this *Resource Guide* concentrates on LNG vehicles, fuels, and facilities, understanding the implications of choosing LCNG can be helpful for decision makers. For example, if your fleet operating site is located far from a pipeline (such as at a remote national park) the liquid version of the fuel may be more practical to transport. At the same time, the more established CNG technology may be more readily available, especially if your fleet consists largely of light-duty vehicles. A fleet in this situation could utilize LCNG to take advantage of the higher energy density of LNG for transporting the fuel and the convenience of CNG for storage of fuel on-board the vehicles. LCNG capabilities can also be added to an LNG fueling station with a modest amount of station modification. This option may be ideal for fleets operating both CNG and LNG vehicles.

How Do We Get Started?

Many demonstration projects for fleets of trucks and buses using LNG in commercial operations have been completed or are underway. During these demonstrations, valuable information has been collected from participating company personnel. Data on operations, maintenance, vehicle performance, and emissions have been analyzed. The engineers and fleet managers also willingly identify lessons learned from each demonstration. Experience has shown that successful implementation of LNG (or any new technology) in fleet operations is built on planning, strong leadership, and commitment.

One of the major lessons learned from LNG vehicle operations is to have realistic expectations of the implementation process and the costs required for start-up and operation. Implementing any major new technology within a fleet will require additional costs, time, and effort. Planning for this extra effort and cost will be the key to avoiding delays and budget overruns. Although some of these costs can be recovered through incentives, it is rare that any of these projects proves cost-effective during the first few years. Beyond being expensive at start-up, such projects are often slow moving, taking a long time to implement and adjust to the new vehicles and related operations. In short, LNG implementation is not a simple process, and it rarely comes with financial benefits at the beginning, but there are reasons that make LNG implementations worth doing (as discussed earlier in **Why Alternative Fuels?**). Some of the most difficult issues in the beginning come down to the newness of the technology and the lack of information available for making good decisions.

Equipment and Operational Differences with LNG

There are many details about the technical changes involved with implementing LNG vehicle operations that you should be aware of before deciding to implement LNG in your fleet. In general, when using new technology like LNG, there will be fewer options available. This will apply to engines, vehicle platforms, fuel suppliers, and many other aspects of LNG operation. Using engines as an example, the heavy-duty natural gas engine offerings from OEMs do not have as many horsepower and torque settings available as conventional heavy-duty engines do.

In addition, this new technology may not perform as well as the conventional systems you have used in the past. Again, using the example of engines, dedicated natural gas engine technology is not as efficient as its diesel counterpart (spark ignition versus compression ignition) especially at low loads and when in idle mode. The natural gas vehicle industry is working on expanding the available options and improving technology performance, but it will take some time for LNG to reach the technological maturity of conventional fuels. Figure 1-2 shows an LNG fueling station in Southern California. Section 2 includes further details regarding the technical differences between LNG and conventional technologies.

Figure 1-2. LNG Fueling Station at Taormina Industries

Implementation Timeline

The implementation of LNG vehicles usually progresses in phases:

- Early planning – collect data, make contacts, and make a plan to move forward.
- Program implementation – complete the purchase process including specifying, ordering, and installing LNG equipment, complete the first round of training activities.
- Start-up – resolve initial problems in the systems, get the vehicles and support equipment up and running on a regular basis, need focus on adequate training and safety procedures.
- Optimization – track and study the vehicle and facility operations, implement changes as appropriate to optimize the operation, resolve problems and issues, integrate training for LNG into standard training activities.

These phases may take two to four years to complete depending on the timing and availability of equipment and support. Running across these time phases are several specific activity categories. Introduction of the new vehicles should be made over time. Furthermore, time must be allowed to troubleshoot, provide training, and educate the staff, management, and local officials. The LNG implementation process is discussed in brief in this subsection by the following categories. Further details regarding specific strategies for LNG implementation are included in Section 2.

- Build the LNG implementation team
- Start early to collect data and build a network
- Build an implementation strategy and plan
- Corporate commitment, communication, and promotion
- The purchasing process
- Planning for early operations and problems
- Training and safety

Build the LNG Implementation Team

This LNG implementation team will be the group that leads every phase and aspect of the LNG implementation. This team will work through the purchasing process and prepare for early operations and problems. As the vehicles and infrastructure come online, this team will evolve from implementation to optimization of the operation of the vehicles and infrastructure, and work to resolve ongoing issues. Once the LNG equipment is up and running, some of the problems may be complex and require study and data collection in order to address each problem properly. This team will lead these troubleshooting activities.

Start Early to Collect Data and Build a Network

Everything about LNG may be new to you at the beginning. It is important to start early in the process of considering the implementation of LNG vehicles by collecting data, building a network of experts, vendors (especially the original equipment manufacturers of the LNG systems), and other fleets, and building the implementation strategy (or roadmap). The hardest parts of implementing LNG vehicles are getting started, finding resources (funding, reports, and web sites for information and background), and finding experts and vendors to begin the process of developing your own LNG vehicle and infrastructure operation experts. At the beginning, what you lack most is experience on which to base decisions.

Before deciding whether or not to implement LNG, you should learn as much as you can about the specific changes that you would need to execute and consider the effects that these changes would have on your fleet. In order to do this, you will need to collect all the information necessary to understand the LNG fuel, LNG technologies, and the best strategies for implementing LNG within your particular fleet. Here are some suggested sources:

- Access all the relevant web sites for background information needed to make good decisions (note: many references to government, commercial, and trade association web sites are included throughout this *Resource Guide*). Tables 1-1 and 1-2 provide a must-have list of reports and web sites that should be considered a starting point.
- Analyze your service routes to determine the number of vehicles needed for your service area and a technical description of your service duty cycle from the vehicle operation perspective.
- Examine your budget and determine what can be allocated for the new LNG vehicles.
- Attend LNG, natural gas, and other AFV conferences and meetings where you can learn more as well as develop contacts and identify support groups; it is especially important to talk with OEM representatives, fuel providers, and LNG users at conferences and exhibits; actively look for funding sources and work to understand available credits. Table 1-3 provides a list of some conference sponsors that should be considered.
- Review environmental and building regulations prior to site planning to accommodate the new fueling infrastructure.
- Contact your local building codes officials and the fire marshal in your area; make sure these officials are included in planning for facility modifications and additions in preparation for LNG.
- Study your facility's site drawings to anticipate modifications and additions.
- Consult with an experienced Architectural & Engineering (A&E) firm with relevant experience specifically in LNG to provide options and accurate cost estimates.
- Obtain descriptions of site modifications, needed infrastructure, and safety equipment needed for your site(s).
- Take tours of similar facilities where LNG facilities have been installed.
- Purchase or gain access to alternative fuels technical manuals for vehicles and infrastructure.
- Attend training courses on LNG vehicles and infrastructure.

Section 3–The Appendix includes listings of reports, web sites, training material, and newsletters and magazines that include information regarding LNG vehicles and infrastructure.

Build An Implementation Strategy and Plan (The Roadmap)

The development of the implementation and strategy plan is critical especially in the early stages of planning for LNG. This plan should describe all of the activities and timing, the business plan for the LNG program (how much money is needed and where is the money going to come from), and an overview of responsibilities of staff for each aspect of the program. This plan needs to be flexible and will need to be modified many times before the LNG operation becomes routine. One of the most important parts of this plan will be the definition of success of the LNG implementation and operation. The plan will need to describe what the goals of the program are and what success is, so that you will know when you have it.

Table 1-1. The Must-Have List of Reports for LNG

Topic/Report	Report Number	Where to Order
General Information		
Liquefied Natural Gas: Alternative Fuel of Choice	CD-ROM	www.nexgenfueling.com
NGV Resource Guide		www.ngvc.org
The Clean Fuels and Electric Vehicles Report		www.energy-futures.com
Funding/Getting Started		
Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations	TCRP Report 38	www.trb.org
Liquefied Natural Gas for Heavy-Duty Transportation		www.gastechnology.org
Natural Gas Buses: Separating Myth from Fact	NREL/FS-540-28377	www.afdc.doe.gov
Natural Gas Vehicle Purchasing Guide		www.afdc.doe.gov
Fleet Start-Up Experiences at the AFDC	Several	www.afdc.doe.gov/pdfs
Vehicles		
Reference Guide for Integration of Natural Gas Vehicle Fuel Systems	GRI-02/0013	www.gastechnology.org
Heavy Vehicle and Engine Resource Guide	NREL/TP-540-31274	www.afdc.doe.gov
Recommended Practices for LNG Powered Heavy-Duty Trucks	J2343	www.sae.org
Vehicle Maintenance and Operating Manuals		From OEMs
Fueling Station and Facilities		
Risk Management Plan Guideline for LNG Vehicle Fueling Stations	GRI-98/0245	www.gastechnology.org
Qualitative Risk Assessment for an LNG Refueling Station and Review of Relevant Safety Issues	INEEL/EXT-97-00827 rev 2	www.inel.gov
Clean Air Program: Design Guidelines for Bus Transit Systems Using Liquefied Natural Gas (LNG) as an Alternative Fuel	DOT-FTA-MA-26-7021-97	www.ntis.gov
Operating Manuals for Safety Equipment including servicing procedures for combustible gas detectors		From OEMs
Safety and Training		
Introduction to LNG Safety		www.ch-iv.com
Clean Air Program: Liquefied Natural Gas Safety in Transit Operations	DOT-FTA-MA-90-7007-95-3	www.ntis.gov
Introduction to LNG for Personnel Safety	X08614	www.aga.org
Introduction to LNG Vehicle Safety	GRI-92/0645	www.gastechnology.org
Clean Air Program: Summary of Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuel	DOT-FTA-MA-90-7007-95-1	www.ntis.gov
Standard for Liquefied Natural Gas (LNG) Vehicular Fuel Systems	NFPA 57	www.nfpa.org
Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)	NFPA 59A	www.nfpa.org
Proceedings of Liquefied Natural Gas Vehicle Systems: Training School		www.nexgenfueling.com

Table 1-2. The Must Have List of Web Site Resources

Web Site	Source Web Site
Alternative Fuel Data Center	www.afdc.doe.gov
Clean Cities	www.ccities.doe.gov
Natural Gas Vehicle Coalition	www.ngvc.org
EPA Office of Technology and Air Quality	www.epa.gov/otaq
Gas Technology Institute	www.gastechnology.org
Alternative Fuel Vehicle Fleet Buyer's Guide	www.fleets.doe.gov
CARB Moyer Program	arbis.arb.ca.gov/msprog/moyer/moyer.htm
Society of Automotive Engineers	www.sae.org
Natural Gas Vehicle Institute	www.ngvi.org
Alternative Fuels Training Consortium	naftp.nrcce.wvu.edu

Table 1-3. Sponsors of Conferences and Meetings that Regularly Include LNG Vehicles

Meetings/Sponsors	Web Site
Natural Gas Vehicle Coalition	www.ngvc.org
Clean Cities, national and local	www.ccities.doe.gov
Society of Automotive Engineers	www.sae.org
American Public Transportation Association	www.apta.com

Another key aspect of this plan is how you phase-in the LNG operation. Having vehicles without fuel or fuel station is not useful. In general, you want facility modifications and installation of the fuel station before anything else. You will want to make sure fuel will be available before or about the time that the LNG vehicles arrive. Training is extremely important and should start well before any of the equipment arrives on-site. You may want to have only a few vehicles arrive at the beginning so that the fueling, facility, and vehicle LNG systems can be checked out and changes made as needed.

Table 1-4 provides a general outline of the implementation strategy and plan (The Roadmap). This document is intended to evolve over time. In the beginning, the document can be used to define the work to be completed. As progress is made, this document can be used to track progress and define new tasks as the need arises. This plan should be defined to best suit your needs. Also, this plan should be updated on a regular basis as the implementation team meets over time.

Table 1-4. General Outline of the Implementation Strategy and Plan (The Roadmap)

Introduction/Background – describe the general factors pushing the use of LNG
Objectives of the LNG Program – success will be based on this
The Implementation Team – describe the staff needed to be involved and responsibilities
Business Plan – estimated costs of the program and where the money is going to come from
Operations – describe the expected use of the LNG vehicles
Vehicles – describe the potential options of technology to choose from
Fuel Purchase – describe the fuel requirements including how much, source, and cost
Support Infrastructure – on-site fueling, facility modifications
Safety – risk management and procedures
Training, Training, Training – every impact of LNG operation must be incorporated into training programs
Phase-In Strategy and Timeline – description of overall timing strategy and progress to date
Action Items – track action items defined and progress towards completion

Corporate Commitment, Communication, and Promotion

Corporate commitment is critical to the success of the LNG implementation. This commitment sets the tone for the organization. Commitment means using funds, personnel, and work time, as well as patience and persistence to absorb this new technology into day-to-day operation. Once the Implementation Strategy and Plan has been completed, this plan needs to be made available to the senior corporate members of the company as well as managers and staff for review, comment, and buy-in. Everyone in the organization needs to eventually buy-in to the LNG implementation if it is to be successful. This will also mean that ongoing and complete communications are necessary for the implementation team, senior management, and the staff.

The Purchasing Process

The purchasing of LNG equipment (or any new technology equipment) requires several steps in chronological order as follows:

- Homework – investigate the options and available products as well as exactly what is needed including funding.
- Specification – determine the appropriate specifications for the equipment needed.
- Order – send out requests for proposal and award a contract for the equipment desired.
- Installation – have the equipment delivered, installed, and tested/verified that it is working properly.

As with any purchase, homework is required to learn about the product options for what you wish to purchase and to match those options to what will best fit your operation. You will also need to study your own operation and fully characterize the requirements for the equipment purchases. This can be done internally or by hiring a consultant experienced in preparing and choosing equipment for LNG operations; however, the transportation company should remain in the lead and control of the implementation. The ultimate goal in this process is for the fleet to operate LNG vehicles in a cost-effective manner as soon as possible, this requires that the fleet become their own expert in LNG vehicle and infrastructure as soon as possible. Figure 1-3 shows an LNG bus at Dallas Area Rapid Transit (DART) in Texas.

Figure 1-3. LNG Transit Bus at DART in Dallas, Texas

Resources:
Heavy Vehicle and Engine Resource Guide, U.S. Department of Energy/National Renewable Energy Laboratory, NREL/TP-540-31274, 2002.
Natural Gas Vehicle Purchasing Guide, RP Publishing, 2002.
NGV Resource Guide, RP Publishing, 2002.

Planning for Early Operations and Problems

As the start-up of LNG vehicle operation comes closer, plans are needed for resolving problems. Assurances of support from the vehicle and fueling vendors will be needed. These assurances should come in the form of having technical staff available to be on-site or be able to provide quick on-site support for problems that arise. The testing of infrastructure equipment and vehicle equipment should be done with only a few vehicles first to work all the final issues out. During all of these activities, the user should have personnel watching and learning about the problems and how to troubleshoot those problems in the future. These activities will be an extra expense, but will be required to optimize the operation in the future. Some sites have had significant issues during start-up that have required days, weeks, even months to resolve.

Training and Safety

The training aspect of LNG operations is also extremely important. All personnel should be aware of the considerations associated with the fact that LNG is a cryogenic liquid as well as a fuel. Personnel who work around or handle LNG should be required to be trained in the proper handling, what to expect, and how to react in case of an accidental spill or vapor release. When using a new fuel and with new equipment on-site, it is important that all personnel are provided with complete and accurate descriptions of the new facilities and receive proper training and information. Further information on training can be found throughout this *Resource Guide*, but especially in the subsection, **What Are the Safety Considerations for LNG Vehicle Operations?**

How Do We Resolve LNG Problems?

Over the course of any new system implementation, problems will occur. LNG is no exception to this rule. As most fleet mangers have probably experienced, any change to the daily fleet operations, even a change as small as implementing a new scheduling or route assignment process, can cause difficulties. These difficulties are magnified when they can have safety ramifications in addition to performance ramifications. The key to addressing these problems when they occur is to anticipate them before they occur. By considering how you would address the many types of problems that can occur with an LNG vehicle operation, you will be better prepared to answer the question: What do I do when my LNG systems don't work?

The best way to prepare for all of the possible problems that may arise concerning LNG vehicle operation is to consider the types of problems that may occur and develop strategies for approaching each problem. When a problem occurs, the first objective will be to determine what the problem is. In order to do this, you must have knowledgeable personnel available to analyze the problem. Training is emphasized throughout this resource guide, but when problems occur is when it will pay off most. Developing as many on-site experts as possible will allow your fleet to address issues quickly and effectively to minimize vehicle downtime, and enhance performance. It is also important to make sure that training is kept up-to-date and personnel are familiar with the basic concepts of LNG vehicle operation and what to do if there is a problem.

An emergency plan, which is discussed further in **What Are the Safety Considerations for LNG Vehicle Operations?**, will address many of these issues. Most of the other issues concern the functionality of vehicles and equipment. Solving these problems will require accessing the proper information, personnel, and equipment. There may also be short-term solutions, which will enhance productivity, such as using spare vehicles or alternate fueling sites. It should be noted that LNG vehicles will vent fuel if not used regularly.

Another important thing to remember when implementing LNG vehicle operations is that this new technology is in the early stages of development. The responsibility will often fall on the operator to solve their own problems and analyze their own systems. It is very important for the fleets to embrace the new technology, not only learning as much as they can about LNG vehicles in general, but also studying the patterns and behaviors of their particular systems and operations to improve overall performance.

What Are the Safety Considerations for LNG Vehicle Operations?

Like any fuel, safe handling procedures, and proper safety precautions must be followed when working with LNG. Many years of experience using NGVs have proven that natural gas can be used safely as a fuel for vehicles. However, using LNG, or any alternative fuel, involves different safety issues than most fleet personnel are accustomed to. The key to safely operating LNG vehicles is considering the procedures, equipment, and training that must be implemented within an LNG vehicle operation. Safety and training should be enhanced by using an architect and engineering firm experienced in LNG for site planning, facility modifications, installations of equipment, and emergency procedures. Training should include expert training available from third parties and vendors. The local codes officials and fire safety personnel should also be included in planning, training, and emergency preparedness exercises.

Effects of LNG Characteristics on Safety

Any consideration of the safety considerations for LNG vehicle operation must include an examination of the characteristics of LNG and how they affect safety considerations. A more detailed discussion of LNG characteristics can be found in the subsection **What is LNG?** Derived from natural gas, LNG is a clear and odorless liquid that, like other forms of natural gas, is not toxic, corrosive, carcinogenic, or a threat to soil, surface water, or ground water. If LNG fuel is spilled, it will dissipate rapidly into the atmosphere, causing no lasting problems for the soil, plants, or animals. Still, LNG vapor can create hazards if they collect in flammable concentrations. Besides vapor ignition, the major safety concern when working with LNG is exposure to cryogenic temperatures, because LNG is a cryogenic liquid. Section 2 discusses more deeply the safety issues related to LNG characteristics.

Keeping in mind the characteristics of LNG is important to avoid hazardous incidents while operating LNG vehicles. Until recent years, LNG had a poor safety image as a result of one accident. In 1944, a tank at a large bulk storage facility ruptured and caused a fire. Following that accident, safety codes were written to prevent future accidents. As long as the safety codes are adhered to, LNG can be safe for vehicle use. For the past several decades, the LNG industry has had significantly fewer accidents than conventional fuel refining and distribution facilities. For further information on the 1944 incident and two other incidents attributed to LNG see "A Brief History of U.S. LNG Incidents" at: www.ch-iv.com/lng.

LNG Codes and Standards

Based on knowledge of LNG characteristics and the experiences of the LNG vehicle industry, several codes and standards have been developed to provide guidelines for the design, production, and modification of LNG vehicles, fueling facilities, maintenance areas, and parking structures. These standards provide an important independent reference to help assess the safety and reliability of equipment designs and facilities modifications. The major LNG codes are listed below:

- NFPA 57 Liquefied Natural Gas (LNG) Vehicular Fuel Systems Code, 1999 Edition
- NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG), 2001 Edition
- SAE J2343 Recommended Practices for LNG Powered Heavy-Duty Trucks, issued January 1997

NFPA 57, NFPA 59A, and SAE J2343 are the primary codes and standards that apply to LNG. These standards are not necessarily required by law. Organizations such as NFPA (National Fire Protection Association) and SAE (Society of Automotive Engineers) create these standards as guidelines, but they are only enforceable as law if a particular state or local government adopts them. Certain states such as Texas and California have developed their own codes[1], though they often are similar to the standards discussed earlier. It is important to know what code if any is enforceable in your area. Even if no codes are enforceable in your area, consideration should be given to specifying that vehicles, fueling stations, and associated structures to conform with at least one of the standards described earlier. In most cases, the codes officials in your area will often have the final say for all buildings and operating facilities. This is why it is so important to include these officials and fire marshals in planning and execution of your LNG operating program.

Potential Hazards Associated with LNG

Like any fuel or any new vehicle technology, there are potential hazards. As long as users are aware of these hazards, they can be accounted for in vehicle and facility design. The specific hazards associated with LNG are discussed in detail in section 2, but a brief list is included here:

- Ignition Sources
- Contact with Fuel
- Asphyxiation
- Pressure Increases Due to Vaporizing LNG

Vehicle Specifications

When vehicles are ordered or designed, they should be specified with at least a minimum level of safety characteristics. In addition to safety features designed into the vehicle, the vehicles must

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[1] Railroad Commission of Texas, *Regulations for Compressed Natural Gas (CNG) and Liquefied Natural gas (LNG)* Available at: www.rrc.state.tx.us/tac/16ch13.html

California Code of Regulations, Department of the California Highway Patrol (CHP) Title 13, Division 2, Chapter 4, Article 2, Compressed and Liquefied Gas Fuel Systems. Available at: ccr.oal.ca.gov/

be operated and maintained in a safe manner in order to avoid hazardous incidents. The material in Section 2 highlights the major vehicle related safety features and practices that are necessary to safely operate LNG vehicles.

For safety purposes, vehicles should be specified to adhere to all applicable codes and standards. This includes any enforceable state or local codes that may apply in your area. LNG vehicles should also be specified with the performance characteristics to perform their intended tasks adequately. This increases safety by preventing the vehicles from being regularly pushed to their performance limits. Using vehicles in a more rigorous manner than they were designed for decreases reliability and can compromise safety. Additional information on specifying vehicles is included in **How Do We Get Started?**

Resource:
Reference Guide for Integration of Natural Gas Fuel Systems, 2002, GRI-02/0013.

Vehicle Operation and Maintenance

After the vehicles have been designed, built, and delivered, there are many important elements involved in keeping LNG vehicles operating safely. Section 2 includes material that presents the major facets of safe LNG vehicle operation and maintenance. Other information sources and training should also be consulted for further information regarding these issues as well as other potential issues.

Fueling Stations and Other Facilities

LNG fueling stations and other vehicle facilities should be designed with many safety features. These features are typically designed to prevent pressure buildup, unsafe fuel releases, fires, and exposure to cryogenic materials. The implementation of these features and the ability of on-site personnel to properly respond to emergency situations will minimize the potential for costly or dangerous incidents. Figure 1-4 shows LNG fueling connectors for fueling a transit bus.

Transporting LNG

LNG is typically transported to the fueling station by truck, similar to conventional vehicle fuel distribution. LNG tanker trucks would be unlikely to rupture, because LNG is transported in a double-walled tank that is stronger than the tanks used to deliver other fuels. The likelihood of a rupture of an LNG container is small unless the pressure relief equipment or system failed completely or an unusual combination of events were to take place (e.g., loss of insulation, along with obstruction of the venting and pressure relief system).

Figure 1-4. LNG Fueling of a Transit Bus

Emergency Response

Important to a facility is the development of an emergency response plan. Even when employees are well trained, facilities are well designed, and proper safety procedures are followed, unforeseen accidents may occur. Events such as natural disasters, fires, power failures, or simple human error may present the facility with an emergency situation. If the emergency is not handled correctly, lives may be lost, property may be damaged, and lasting damage to the environment may occur. A good emergency response plan will contain the situation and bring things back to normal as soon as possible. Section 2 includes a detailed description of the main components of an emergency response plan.

Safety and Training

Safety and risk considerations of any fuel for transportation are voluminous, especially if it is new to the facilities and operation. It is important to ensure that personnel are trained to know the properties of LNG and to know proper safety procedures pertaining to LNG fuel and vehicle use. Personnel involved in the fueling and/or use of LNG vehicles, including but not limited to mechanics, drivers, supervisors, engineering staff, and fueling personnel, should receive training in the proper use of LNG. This training may be obtained from supplier schools, original equipment manufacturers (OEM), mechanic schools, and internal training. LNG safety procedures should be integrated into the existing facility standard operating procedures (SOP).

Is LNG Readily Available?

As noted earlier, natural gas is abundantly available from both domestic and North American suppliers. At projected levels of consumption, natural gas supplies will meet U.S. demands for at least 60 years, with non-conventional supplies capable of providing an additional 200-year supply. There is significant LNG production capacity in the United States in addition to significant LNG transported here from outside the United States by large ships. Government forecasts suggest that LNG will be readily available for the foreseeable future and also suggest that its price is likely to remain competitive among transportation fuels.

In local terms, while a network of public natural gas fueling stations is developing for CNG, public LNG fueling stations are not yet available in most areas. In the near term, LNG will be best suited for fleet vehicles that return to a central facility for fueling, though this may change in the long-term if public LNG fueling stations become available. Such a network could develop in some areas if current efforts to build and distribute small-scale liquefaction plants are successful. One such network being developed in the western U.S. is the Interstate Clean Transportation Corridor (ICTC).

North American LNG Production and Distribution

Most LNG in the United States is produced at storage locations operated by natural gas suppliers and at cryogenic extraction plants in gas producing states. In most cases, these suppliers produce LNG and store it for use during periods of high winter (heating) demand for natural gas. The process of adding natural gas from LNG (or other gaseous hydrocarbons) to the normal distribution lines during periods of high demand is known as "peak shaving". In a 1998 report by Zeus Development[2], 120 facilities in the United States were identified as producing LNG as part of normal operations. A handful of the large-scale liquefaction facilities in the U.S. provide LNG fuel for transportation uses (see the map below, Figure 1-5). These suppliers have capacities normally ranging from 50,000 to over 600,000 gallons per day. A fleet of 100 transit buses would be expected to use approximately 5,000 to 8,000 gallons of LNG fuel per day.

Current Availability vs. Potential Availability

It is estimated that about 7,566,000 gasoline gallon equivalent (GGE) of LNG are used annually within the U.S. for transportation fuel. As stated earlier, in the United States, 120 plants produce or store LNG as part of their normal operations. Of these, 59 generate LNG for peak shaving applications and seven plants sell LNG for motor fuel use. Consequently, there is a significant capacity in the United States for producing LNG that could be tapped for motor-fuel purposes if the market demand were to increase. In most of these cases, these plants can be readily shifted to LNG production if there were sufficient economic incentive. One of the major barriers is available and reliable transportation to the fleet's site at a reasonable cost. Small-scale

[2] Zeus Development, LNG Vehicle Markets and Infrastructure, GRI-98/0196, 1998.

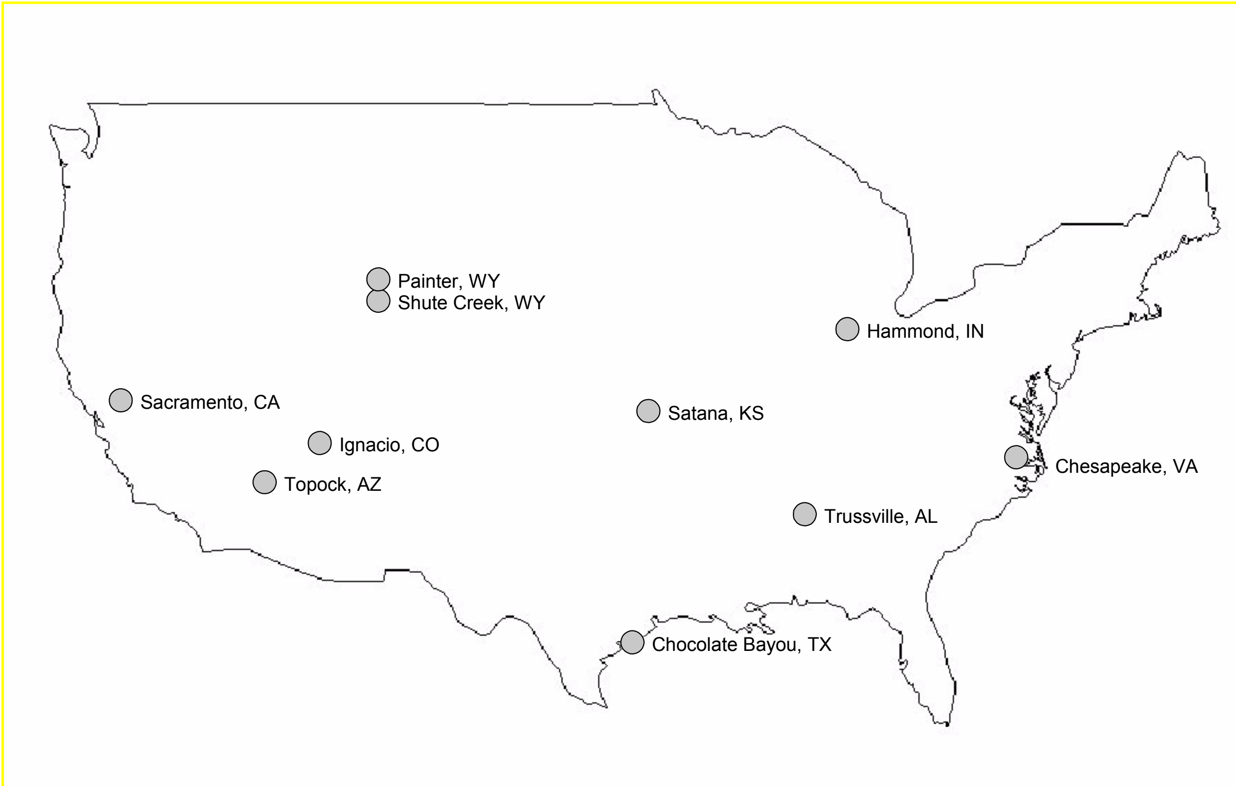


Figure 1-5. Locations of LNG Production Plants in the U.S.

liquefaction, described in more detail in Section 2, may also add significant LNG motor fuel capacity in the future if commercially successful.

Local Availability Issues

LNG is typically purchased directly from the producer by the load or a long-term contract. The transportation of the fuel is contracted separately from an LNG shipping company. JB Kelley is one example of a company that delivers LNG. Most operators purchase LNG in truckload batches of roughly 10,000 gallons delivered 2 to 4 times per week depending upon fuel usage. Transportation costs often make up a significant portion of the cost of LNG, and it is generally not economical to transport LNG farther than 500 miles in any direction from the LNG production location.

Sources of LNG

There are several different techniques for creating LNG. It is important to understand the source of your LNG and how the operations of that source could affect the availability of LNG. The current and potential means of LNG production are listed below:

- Peak Shaving Plants
- Nitrogen Rejection Units and Other Industrial Plants
- Small-Scale Liquefaction
- Landfill Gas

Issues to Consider for LNG Availability

The supply network for LNG motor fuel is not as mature as that for conventional fuels. There is the potential for interruption of supply for a variety of reasons. Hence, when implementing LNG vehicles in a fleet, special consideration will be needed concerning LNG supply and transportation. Issues to consider include:

- Guarantee of supply from the producer
- Supply during scheduled and unscheduled shutdown of the production plant
- Potential backup supply in case of scheduled or unscheduled loss of production
- Regional availability of transportation (tanker trucks) for fuel
- Transportation interruption – potential for labor strikes or roadway blockage such as blocked mountain passes during cold weather
- Added cost of backup supply and transportation in case of interruptions

What Will This Cost Me?

The general path to cost-effective implementation of LNG vehicles into your fleet will require doing your homework, creating a network of resources and contacts, working with experts in LNG, and building your own expertise in LNG. The costs associated with using LNG vehicles will differ in many cases from the costs associated with conventional vehicles. The cost of the LNG will generally be lower than diesel on an energy equivalent gallon basis. However, this lower fuel cost may not translate into overall savings because natural gas engines generally have lower fuel efficiencies than diesel engines. The optimal situation for achieving reduced fuel cost with LNG is in high-mileage, high-speed applications. There may be cases where the price of LNG will be low and translate into significant cost savings.

Experience has shown that once maintenance personnel become familiar with maintaining LNG vehicles, the maintenance costs associated with LNG vehicles are typically only slightly higher than those costs associated with diesel vehicles. To overcome the additional costs associated with purchasing and operating LNG vehicles, fleet mangers may be able to obtain funding from federal, state, and local governmental agencies. In addition to funding, there may be tax breaks associated with the use of LNG that fleets can also take advantage of.

Although using LNG may require additional economic burdens even with funding incentives and tax breaks, fleets should consider the value of using environmentally friendly vehicles. This environmental contribution can help improve the image of your organization in the eyes of your employees, your customers, and your surrounding community. This subsection will outline the costs that may be associated with implementing LNG vehicles. All of these costs should be carefully considered before committing to using LNG, but fleet managers should consider the benefits of LNG as well.

Truly determining the costs of using LNG will require taking a close look at the options available in your area and the necessary costs that will impact your individual fleet. The following suggested tasks, organized by the aspects of operation that they pertain to, will help you to understand what your costs will be and help you to make final decisions.

Vehicles

- Identify representatives available from engine, vehicle, and fuel manufacturers who can help with initial planning, problem solving and trouble-shooting. This can save you hours of staff time during the planning, start-up phase, and full-scale operations.
- Estimate the power needs and range of your specific vehicles.
- Decide how to stage the purchase, replacement, and delivery of the new vehicles.
- Clearly define the operational differences related to the new fuel (e.g., how operations will change with regard to training drivers, fuelers, and maintenance personnel, as well as range, fuel availability, and power).
- Calculate the usage of the vehicles (e.g., amount of fuel used per mile).

Facilities – Fueling, Maintenance, and Others

- Examine the effects of using LNG on your current site layout.
- Determine the cost to modify or construct vehicle maintenance and storage facilities.
- Determine the size of the fueling station(s) and type of fuel storage facility.
- Solicit fuel cost estimates and select a preferred vendor.
- Determine the staff time and cost of regulatory preparation steps, obtaining permits, consulting with safety and fire officials, and addressing building codes.

Operations and Training

- Examine the cost of training (and retraining) personnel involved in operating, maintaining, fueling, or supervising the new fleet.
- Develop methods to track the fuel, performance, maintenance costs, and personnel issues for comparison with vehicles using gasoline or diesel fuel.
- Determine potential roadblocks or problems and prepare workarounds in advance.
- Ask representatives of companies that recently installed an LNG facility what lessons they learned during the process of switching to and using LNG.

The cost of operating an LNG fleet will vary depending on location, preparedness, and size of operation. By gathering enough information, however, fleets can begin to grasp what costs will be associated with using LNG vehicles and making them successful. Section 2 provides additional information about cost factors; training personnel; short- and long-term cost increases; as well as capital investments.

Where Can I Find More Answers?

There are several sources available to provide answers to many of your questions. These sources include companies that supply LNG, consultants who provide advice to potential users of LNG, and companies with fleets powered by LNG. Additional information and lists of LNG suppliers, consultants, and fleets using LNG in routine operations are available in this guide.

Several federal and state government web sites, and the U.S. Department of Energy's Alternative Fuel Data Center (AFDC) web site provide access to alternative fuel reports, brochures, analyses of LNG demonstrations, and documents and publications that may be useful. Here are web site addresses that may be useful for fleet managers who are considering adding LNG vehicles to their fleets:

- Alternative Fuels Hotline: 1-800-423-1DOE
- Alternative Fuels Data Center: www.afdc.doe.gov
- DOE's Office of Transportation Technologies: www.ott.doe.gov
- DOE's Office of Transportation Technologies, Heavy Vehicle Projects: www.ctts.nrel.gov/heavy_vehicle or www.ctts.nrel.gov/ngngv
- Clean Cities Program: www.ccities.doe.gov
- California Energy Commission—About Natural Gas Vehicles: www.energy.ca.gov/afvs
- California Air Resources Board, Moyer Program: arbis.arb.ca.gov/moyer/moyer.htm
- Calstart: www.calstart.org/fleets
- National Association of State Energy Officials: www.naseo.org/energy_sectors/stateenergy (click on alt fuels)
- Natural Gas Vehicle Coalition: www.ngvc.org (especially the NGV Resource Guide)
- Cummins Westport: www.cumminswestport.com

SECTION 2

THE SCIENCE & DETAILS

Topic, Page

What's In This Section?

This section provides more details about alternative fuels, federal regulations, incentives offered to encourage the use of alternative fuels, LNG's operational requirements, advantages and disadvantages, and use of LNG as a transportation fuel. Background information about LNG is also included, e.g., where LNG comes from, what the fuel's properties are, fueling infrastructure, and on-board fuel systems design.

Why Alternative Fuels?

There are several reasons to consider the use of alternative fuels. These reasons will usually include all or a combination of the following: local and/or federal regulations require my fleet to seriously consider the use of cleaner fuels, local and/or federal incentives make the use of alternative fuels attractive for my operation, and the fuel cost and cost of alternative fuel operation in conjunction with incentives makes the use of alternative fuels attractive. Many fleets also can take advantage of the positive impression that the use of cleaner burning fuels can bring from the public and local regulators to their operation such as for garbage trucks and transit buses.

Alternative vehicle fuels have been available as long as gasoline and diesel fuels. However, in the early stages of vehicle development diesel- and gasoline-powered vehicles won out and have been the conventional vehicles of choice for nearly 100 years. Today, transportation vehicles use approximately 68% of all the petroleum consumed in the U.S. and account for about 27% of the total energy consumption in this country[3]. Over the past decade, the return to alternative fuels has been accelerating due to government incentives brought on by environmental and energy security concerns.

Natural gas has been the alternative fuel of choice for the transit bus market and the medium- and heavy-duty truck market. The number of compressed and liquefied natural gas vehicles (NGVs) has grown steadily over the past 10 years (see Figure 2-1)[4]. For example, a survey performed in 2001 by the American Public Transportation Association (APTA) reported the following:

- 5,147 (9.3 percent) of the 55,190 buses in the APTA survey were powered by an alternative power source.
- The majority of those alternative fuel buses were powered by natural gas (4,979 buses or about 97 percent).
- Among the 4,979 buses powered by natural gas were 842 powered by liquefied natural gas (LNG), and the remainder was powered by compressed natural gas (CNG).

The APTA survey includes about 300 transit agencies and represents about two thirds of the transit buses in the U.S.

Web Site References:
Energy Information Administration: www.eia.doe.gov
American Public Transportation Association: www.apta.com
Bureau of Transportation Statistics: www.bts.gov

[3] Davis, S., Transportation Energy Data Book: Edition 21, Oak Ridge National Laboratory, October 2001.

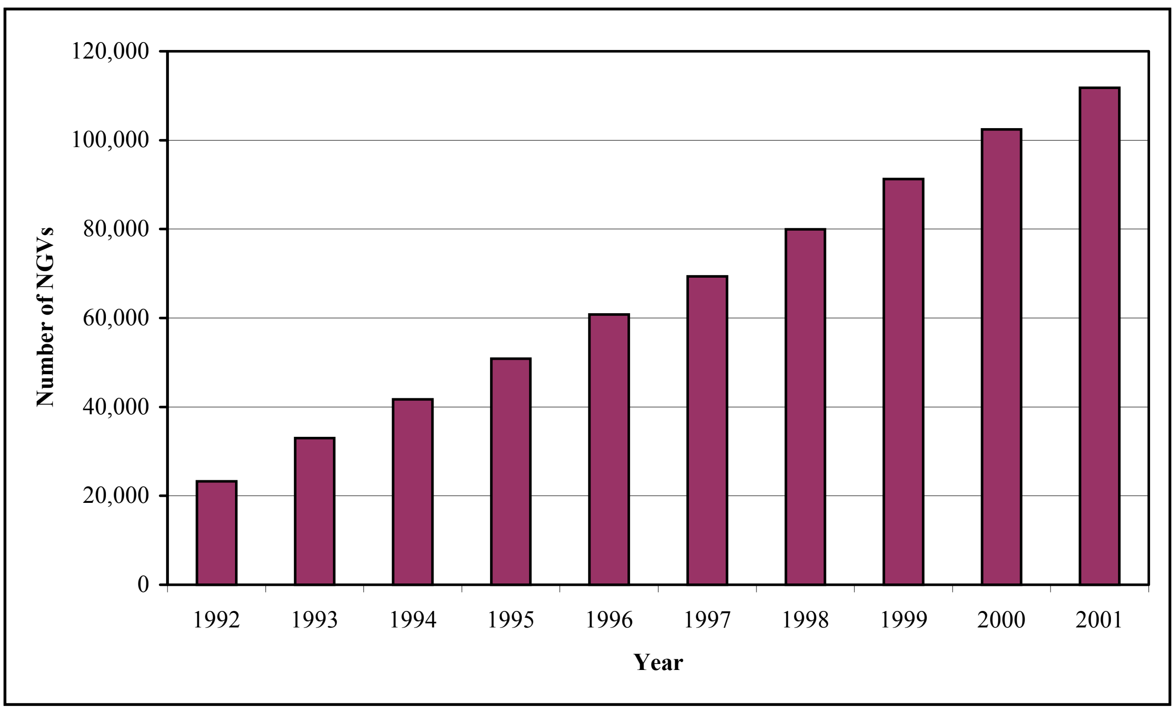
[4] Alternatives to Traditional Transportation Fuels 1999, Energy Information Administration (EIA).

Alternative Fuel Descriptions

The definition of alternative fuels may vary slightly depending on the state where the vehicle is used. Here is a summary of alternative vehicle fuels in use today:

- **Natural gas** (compressed and liquefied)—Natural gas is a mixture of hydrocarbons and is produced either from gas wells or in conjunction with crude oil production. Natural gas has been used for many years as a vehicle fuel by U.S. utility companies. Natural gas is widely used in residential, commercial, industrial, and utility markets—and, since the 1980s, has become a transportation fuel. It has become a popular alternative fuel because of its domestic sources and growing commercial and public availability through an existing network of natural gas pipelines. The chemical components of natural gas are methane, a relatively unreactive hydrocarbon, other hydrocarbons such as ethane and propane, and other gases (such as nitrogen, helium, carbon dioxide, hydrogen sulfide) and water vapor.

  The fuel can be stored on-board a vehicle in either a compressed gaseous state (CNG) or in a liquefied state (LNG). CNG fuel is odorized (a smell like rotten eggs); however, LNG is not odorized because the odorant would solidify in the cold temperature. LNG is produced by cooling natural gas and purifying it to a desired methane content. LNG is a popular alternative to diesel because it has a high-energy content per unit volume and is comparable to gasoline and diesel in time to fuel large vehicles. Additional information about LNG, is provided in the subsection titled **What Is LNG?**



Source: Energy Information Administration (EIA)

Figure 2-1. Growth of Natural Gas Vehicles Over the Past 10 Years

- **Alcohol fuels** (ethanol and methanol)—Ethanol and methanol are the primary alcohol fuels available for vehicle use. While both fuels are alcohols, they have different feedstocks or sources. The Clean Air Act Amendments of 1990 mandated the sale of oxygenated fuels in areas with unhealthy levels of carbon monoxide, and this has increased the demand for alcohol fuels. Ethanol and methanol have similar chemical and physical characteristics. Ethanol, also referred to as ethyl alcohol or grain alcohol, is a clear, colorless liquid. It can be blended with gasoline (e.g., 10 percent ethanol and 90 percent gasoline) to increase the octane and decrease the emissions from gasoline. Ethanol blends in low percentages by volume can be used in all types of vehicles and engines that use gasoline. These blends of gasoline and ethanol are often referred to as gasohol. Ethanol vapors are relatively non-toxic compared to gasoline, according to studies. An ethanol blend of up to 85% by volume (E85) has been used in several OEM light-duty vehicles (especially since model year 1998).

  Methanol, also known as wood alcohol, is produced by steam reforming natural gas to create a synthesis gas, which is then fed into a reactor vessel in the presence of a catalyst to produce methanol and water vapor. Synthesis gas is a combination of carbon monoxide (CO) and hydrogen that is fed into the reactor vessel under high temperatures and pressures where CO and hydrogen are combined. The reactor product is distilled to purify and separate the methanol from the reactor effluent. Alcohol fuels have achieved some success in vehicle use over the past two decades. However, this fuel is generally no longer in use. The last OEM light-duty vehicle to be capable of using a blend of methanol (M85, 85% methanol by volume) was the 1997 Ford Taurus.

- **Clean diesel** (biodiesel, ultra-low sulfur diesel, natural gas-derived diesel)—Clean diesel fuels may include biodiesel, special diesel formulations, such as ultra-low sulfur diesel (ULSD), and natural gas-derived diesel fuel from the Fischer-Tropsch process. Biodiesel is a replacement fuel made from natural, renewable sources such as vegetable oils. Biodiesel in small percentages by volume (usually up to 20% by volume – B20) can be used in compression-ignition engines without engine modifications, and has the energy level and range of diesel fuel. Used in a conventional diesel engine, B20 can result in substantially reduced emissions of unburned hydrocarbons (HC), CO, sulfates, particulate matter (PM), and other toxic air contaminants. Biodiesel by itself (B100) as a fuel can show higher oxides of nitrogen (NOx) and may require changes to the engine control. Diesel engine manufacturers should be consulted to determine the optimal usage of biodiesel.

  Ultra-low sulfur diesel fuels (e.g., less than 15 parts per million [ppm]) are now being sold in several states. Studies show that ULSD allows the use of more active catalysts in conjunction with soot filters (diesel particulate filters – DPF). The function of the catalyzed filter is to remove PM, or soot, gaseous emissions, CO and HC, as well as the characteristic odor of diesel fuel emissions.

Diesel fuel can also be made synthetically with a process such as Fischer-Tropsch, which processes natural gas into a fuel similar to diesel fuel with low sulfur and low aromatics content. This fuel has shown the ability to significantly reduce diesel engine emissions in studies.

- **Electricity**—With this fuel, mechanical power comes directly from electricity to power motors, which is quite different from the other alternative fuels that release stored chemical energy through combustion. The main benefit of an electric motor is there are no tailpipe emissions. The downsides are the initial capital cost and range limitations (typically 60 to 150 miles on a single battery charge). On-board rechargeable batteries (or potentially other energy storage devices such as ultracapacitors in the future) power the electric motor. Electricity used to power personal or fleet vehicles can be provided for battery charging by standard 110- or 220-volt outlets transferred to batteries, e.g., lead-acid, nickel cadmium, nickel iron, or sodium nickel chloride. Full charges take four to eight hours but special 440-volt outlets can charge to 80 percent in less than an hour. Special training may be required to operate and maintain electric vehicles.

  A new alternative fuel propulsion technology for heavy-duty vehicles currently being demonstrated and tested uses batteries coupled with a diesel engine powering a generator to recharge the batteries. This technology is known as diesel hybrid electric propulsion and can significantly extend the range of an electric vehicle. Hybrid electric vehicles allow the use of regenerative braking. Regenerative braking takes advantage of the energy that is normally turned into heat during braking by converting it into electrical energy. This energy can then be stored in the vehicle batteries and used later to power the vehicle. This technology prevents some energy losses providing greater fuel and energy efficiency, which can reduce emissions. This type of braking can reduce wear of the brakes as well.

- **Hydrogen** (for fuel cells and internal combustion engines)—Fuel cells fueled by hydrogen have been used to power electric equipment on spacecraft for many years. Fuel cell vehicles combine hydrogen fuel from the vehicle's fuel tank and oxygen from the air to generate electricity that powers an electric motor, just like electricity from batteries does for a regular electric vehicle. When hydrogen and oxygen combine, they give off energy and water—but no emissions from the tailpipe except water. Gaseous hydrogen can be carried on a vehicle if it is compressed and stored in high-pressure containers, similar to the method used for CNG vehicles. Hydrogen can also be liquefied for on-board storage. There is also hope that on-board fuel reformers may be able to pull the hydrogen out of any fuel composed of hydrocarbons, such as gasoline, natural gas or methanol. Research funded by the U.S. Department of Energy is underway to develop, by 2004, highly efficient low- or zero-emission automotive fuel cell systems that can be powered by hydrogen, methanol, ethanol, natural gas, or gasoline.

  Hydrogen can also be used directly in internal combustion (IC) engines to power vehicles. Hydrogen can be used in IC engines by itself or combined with natural gas. These technologies are in the relatively early stages of development, yet they have more potential to reduce emissions than any other internally combusted fuel.

- **Propane**—Liquefied petroleum gas (LPG) consists mostly of propane, propylene, butane, and butylene in various mixtures. The mixtures in the U.S. are mainly propane, which is a byproduct of natural gas processing and crude oil refining. LPG's components are gases at normal temperatures and pressures. Propane has the lowest flammability range of any alternative fuel and is a nontoxic, nonpoisonous fuel that does not contaminate aquifers or soil. Propane leaks are easily detected because an odorant (similar to rotten eggs) has been added. Nearly 270,000 vehicles—mostly in fleets—are currently using propane in light- and medium-duty vehicles, such as taxis, school buses, and police cars.

Blends of any of these alternative fuels with gasoline or diesel fuel, as well as other chemicals, may also be considered part of the alternative fuels group. These fuels are currently powering a variety of vehicles, including heavy-duty trucks, garbage packers, dump trucks, snowplows, package delivery vans, buses, taxicabs, and other passenger cars.

Web Site References:
Energy Information Administration: www.eia.doe.gov
U.S. Department of Energy, Clean Cities: www.ccities.doe.gov
U.S. Department of Energy, Alternative Fuels Data Center: www.afdc.doe.gov

Legislative Drivers

The current focus on alternative fuels, cleaner air from mobile sources, and energy security has evolved significantly since 1988, due principally to substantial federal legislation. Government regulations to reduce air pollution and public concerns about harmful emissions from transportation vehicles are driving the use of alternative vehicle fuels. Using alternative fuels in transportation vehicles can reduce air pollution as well as the nation's dependence on foreign oil, because most of the alternative fuels are widely available in the U.S. from relatively local sources.

Several acts that have renewed and sustained the interest in alternative fuels are:

- Alternative Motor Fuels Act 1988 (AMFA)
- Clean Air Act Amendments of 1990 (CAAA)
- Energy Policy Act of 1992 (EPAct)
- Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA)
- Transportation Equity Act for the 21st Century of 1998 (TEA-21)

The provisions of the AMFA, CAAA, EPAct, ISTEA, and TEA-21, and other federal and state legislation require a gradual transition of some fleets from conventional fuels, gasoline and diesel, to alternative fuels. These regulations also include requirements for monitoring emissions and providing incentives to potential users of alternative fuel vehicles (AFVs).

Two federal agencies, the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE), have enabled and promoted the movement to AFVs. The EPA has been driving the use of alternative fuel by implementing more stringent mobile source emissions requirements. DOE has taken the lead among federal agencies in promoting the use of alternative fuels by funding or co-funding alternative fuel vehicle demonstration and evaluation projects. These alternative fuel projects help DOE to ensure energy security by promoting domestic fuel sources, and decreasing dependence on oil reserves in foreign countries.

During the late 1980s and early 1990s, federal agencies led the way by requiring federal fleets to transition to AFVs, many of which chose CNG. Many states followed with additional regulations and their own incentive programs to promote and increase the use of alternative vehicle fuels. The most prominent of these states is California, the state setting the pace for emissions regulations as well as incentive programs, although many others are following California's lead.

Many of the emission-reduction goals in national legislation are based on purchases of alternative fuel vehicles as a percentage of total vehicle purchases. On that basis, the purchase of alternative fuel vehicles has not been as successful as originally envisioned. But the availability of alternative fuel vehicles has caused conventional fuel and vehicle providers to find ways to reduce vehicle exhaust emissions significantly in order to meet certification levels over the last 15 years and into the future, as shown in Table 2-1. The fuel providers and vehicle manufacturers have been extremely successful in reducing toxic exhaust emissions, while improving vehicle performance and safety.

In August 1998, the California Air Resources Board (CARB – the regulatory body in California for air quality protection) designated diesel particulate emissions as a toxic air contaminant (TAC). A TAC in California is defined as an air pollutant which may cause or contribute to an increase in mortality or in serious illness, or which may pose a present or potential hazard to human health[5]. Since CARB designated diesel particulate emissions as a TAC, the pressure on heavy-duty engine manufacturers to reduce particulate emissions has been severe. The U.S. Environmental Protection Agency has not followed suit with CARB; however, there is a general consensus that the reduction of diesel particulate emissions is extremely important for cleaner air. Many studies are under way to determine the severity of the toxicity issues with diesel particulate emissions.

Greenhouse gases (GHG) are another pressure on the reduction of heavy-duty engine (and all engine) emissions. Greenhouse gases generally include water vapor, carbon dioxide (CO_2), methane (CH_4), and oxides of nitrogen (NOx). The greenhouse effect is a natural process that keeps the surface of the earth warmer than the space surrounding the earth. Greenhouse gases in the atmosphere allow some of the solar radiation reflected off the earth's surface to be re-emitted back towards the earth, rather than releasing all of this solar radiation back to space. The net effect is a warming of the earth's surface and its lower atmosphere. Figure 2-2 shows a graphical representation of the greenhouse effect. Over the past 10 to 20 years, there has been growing concern with the increase in the concentration of the greenhouse gases, and the potential effect that these increases may have on the climate of the earth.

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[5] California Health and Safety Code, Section 39655.

Table 2-1. EPA Emission Standards for Heavy Duty Engines

Model Year	Exhaust Emissions (g/bhp-hr)				
Diesel Truck	**THC**	**NMHC**	**NOx**	**CO**	**PM**
1991	1.3		5.0	15.5	0.25
1994	1.3	1.2	5.0	15.5	0.10
1998	1.3	1.2	4.0	15.5	0.10
2004[a]	1.3	2.4, 2.5[b]		15.5	0.10
2007	1.3	1.2	0.2	15.5	0.01
Diesel Transit Bus	**THC**	**NMHC**	**NOx**	**CO**	**PM**
1994	1.3	1.2	5.0	15.5	0.07
1996	1.3	1.2	5.0	15.5	0.05
1998	1.3	1.2	4.0	15.5	0.05
2004[a]	1.3	2.4, 2.5[b]		15.5	0.05
2007	1.3	1.2	0.2	15.5	0.01
Federal Clean Fuel Fleet Vehicle Standards					
	THC	**NMHC**	**NOx**	**CO**	**PM**
LEV – Federal	--	3.8[b]		14.4	0.10
LEV – California	--	3.5[b]		14.4	0.10
ILEV	--	2.5[b]		14.4	0.10
ULEV	--	2.5[b]		7.2	0.05

a – These emissions levels have been moved ahead to October 2002 for OEMs included in an EPA Consent Decree

b – 2.4 NMHC + NOx or 2.5 NMHC + NOx with a limit of 0.5 on NMHC

Table 2-1. Acronym List

THC – total hydrocarbons
NMHC – non-methane hydrocarbons
NOx – oxides of nitrogen
CO – carbon monoxide
PM – particulate matter
LEV – low emission vehicle
ILEV – inherently low emission vehicle
ULEV – ultra-low emission vehicle

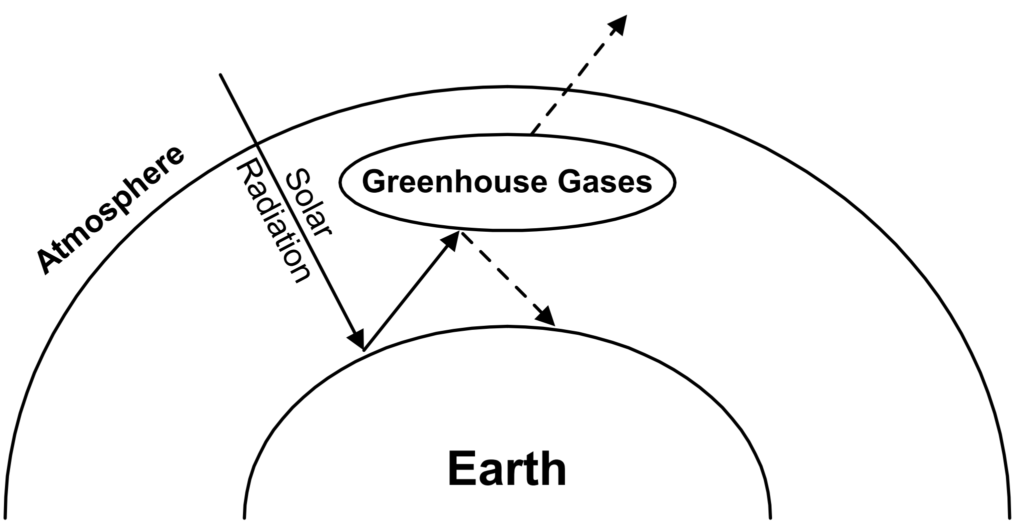

Figure 2-2. Greenhouse Effect

Since the start of the industrial revolution, carbon dioxide concentration in the atmosphere has increased 30%, methane has increased 100%, and oxides of nitrogen have increased 15%. Carbon dioxide is often considered the general indicator of increased greenhouse gases. Scientists generally believe that burning fossil fuels and other human activities are the primary reasons for the increased concentration of carbon dioxide. Fossil fuels are used to power cars and trucks and heat homes, businesses, and industrial centers. These fossil fuels are responsible for many other potentially toxic emissions. About 98% of the carbon dioxide, 24% of the methane, and 18% of the oxides of nitrogen in the atmosphere are attributed to the use of fossil fuels[6].

Greenhouse gases and regulated emissions are produced from vehicles, stationary engines, and from the development and delivery processes of providing the fuels to market, called fuel-cycle emissions. From a greenhouse gas emissions standpoint, many believe that a given fuel must be studied from the extraction process through the actual use or combustion of the fuel in a vehicle in order to understand the full emissions impact and energy efficiency of using a fuel type. In order to properly evaluate energy and emissions impacts of vehicle technologies, the fuel cycle from "well to wheels" and the vehicle cycle need to be considered. The U.S. Department of Energy through the Argonne National Laboratory has developed a modeling tool to complete this type of analysis – the Greenhouse Gases, Regulated Emissions, and Energy use in Transportation (GREET) model. There have been some issues raised about model additions regarding inputs of this model in respect to sources of fuels such as natural gas in terms of domestic versus import sources and how the use of wind power for electricity would impact these analyses. As with any model analysis, you need to clearly understand the assumptions and the inputs of the model in order to interpret the results properly.

In response to the concerns with vehicle emissions, the standards for mobile emission levels are expected to become much more strict with a phase-in of reductions starting in 2007 (see Table 2-1). These new standards will be especially strict on emissions of particulate matter (PM) and oxides of nitrogen (NOx). These standards will require that tailpipe emissions be significantly reduced from current levels by 2010, when the standards will be fully implemented. In order to meet these more difficult requirements, both diesel and natural gas engines will be required to change how NO_x is controlled and what aftertreatment devices are used. Both diesel and gasoline fuels must reduce sulfur levels as well in order to enable the use of more active catalysts in aftertreatment devices. Today's standard for diesel is 500 parts per million (ppm) sulfur, and the future standard will be 15 ppm sulfur by 2006. Vehicles will be allowed to use more active catalysts and aftertreatment devices, such as catalyzed diesel particulate filters (DPFs), because of the lower sulfur level in diesel fuel (called ultra-low sulfur diesel – ULSD). California, New York, and other parts of the country already have limited distribution of ULSD. The CARB has verified a number of catalyzed DPFs for on-road heavy-duty vehicles in California.

From an energy security perspective, results of the legislation designed to promote the use of domestically produced alternative fuels have been disappointing. There has been no significant reduction in dependence on foreign oil. In fact, consumption of petroleum-based fuels continues

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[6] EPA Global Warming web site, www.epa.gov/globalwarming/climate/index.html.

to increase, and fuel economy for most light-duty vehicles (at least those vehicles classified as minivans and sport utility vehicles) has gone down as a fleet average. Although a large number of alternative fuel vehicles have been purchased, this has not had a significant impact on petroleum consumption because few of the light- and medium-duty alternative fuel vehicles that have been purchased are dedicated vehicles. Dedicated vehicles can operate only on the alternative fuel for which they were designed. Most of the medium- and light-duty alternative vehicles are bi-fuel (operates on the alternative fuel or conventional fuel) or dual-fuel (can use an alternative fuel, conventional fuel, or some combination). Surveys indicate that most alternative fuel vehicles that can operate on gasoline or diesel fuel, operate almost exclusively on those fuels rather than the alternative fuel[7]. The reluctance to use alternative fuels has been attributed to the lack of fueling infrastructure. In other words, there are not enough places to fuel the vehicles with alternative fuels, therefore, the drivers tend to use only conventional fuels.

Speaking before the U.S. Senate Committee on Finance (July 2001), Jim Wells (Director, National Resources and Environment, General Accounting Office) commented on the GAO's position on the barriers to sustained alternative fuel vehicle introduction in the U.S. The barriers that have impeded the introduction of alternative fuel vehicles are as follows:

- The relatively low price of oil
- Insufficient availability of alternative fuel refueling infrastructure
- The relatively higher cost of certain alternative fuel vehicles

The U.S. Congress has supported and encouraged the use of alternative fuels through tax incentives with exemptions, credits, and deductions, yet AFVs have not been widely adopted. Jim Wells explains, "Alternative fuels and vehicles have not made much of a dent in the conventional fuel and vehicle dominance of the U.S. vehicle fleet, primarily because of the fundamental economic obstacles. As reported in the GAO report of February 2000, any significant increase in the use of alternative motor fuels and vehicles by the general public will depend on two main factors: (1) a dramatic and sustained increase in the price of gasoline and diesel and (2) very large incentives, far above the current levels, to reduce the cost of using alternative fuels and vehicles. Depending on what happens to conventional fuel prices, these incentives would likely need to be maintained for some time – at least until the number of vehicles reaches the level necessary to support an economically sustainable infrastructure[8]."

Web Site References:

U.S. Environmental Protection Agency (EPA): www.epa.gov/otaq/
California Air Resources Board (CARB): www.arb.ca.gov
Intergovernmental Panel on Climate Change (IPCC): www.ipcc.ch
U.S. Department of Energy, Office of Transportation Technologies: www.ott.doe.gov
U.S. General Accounting Office: www.gao.gov
U.S. Department of Energy/Argonne National Laboratory, GREET: www.transportation.anl.gov/ttrdc/greet/

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[7] GAO, Limited Progress in Acquiring Alternative Fuel Vehicles and Reaching Fuel Goals, Energy Policy Act of 1992, February 2000.

[8] GAO, Impact on the Transportation Sector, Alternative Motor Fuels and Vehicles, July 2001, GAO-01-957T.

Incentives

(Note: Most of the information about incentives in this subsection is excerpted from various web sites and some of it may be outdated, e.g., incentive amounts, grants, or government tax deductions. Please contact the Clean Cities Program Office in your state for current information. Clean Cities contacts in each state can be found by clicking the Clean Cities Coordinators link on the Clean Cities Contact web site: www.ccities.doe.gov/contact.shtml. Do your homework as well, tapping into the web sites of trade associations for the various fuels, federal and state agencies, fuel providers, and vehicle manufacturers. Web links for many of these sources are listed in ***Section 3–The Appendix.****)*

Several federal agencies offer financial incentives and in-kind support to increase the development, production, and sales of AFVs. The main federal incentives for purchasing or converting individual AFVs are the federal income tax deductions for clean fuel vehicles ($2,000 to $50,000), available through the Internal Revenue Service in the U.S. Department of Treasury. For example, a new qualified clean fuel truck or van with a gross vehicle weight of more than 26,000 pounds would qualify for an income tax deduction of $50,000. Income tax deductions are also available for installing refueling or recharging facilities for AFVs. There is also ISTEA/TEA-21 legislation for congestion mitigation and air quality (CMAQ) projects. The EPA has a voluntary diesel retrofit program that matches fleet operators, engine manufacturers, and local governments with providers of technology resources to promote the use of cleaner fuels.

DOE's Office of Transportation Technologies (OTT) has developed guides and information to help fleet managers and companies make informed decisions and more easily switch to alternative fuels. The *Fleet Buyer's Guide*—which is designed to help fleet managers understand the relevant regulations and incentives, based on their facility locations and company descriptions—can be reviewed or downloaded from the following web site: **www.fleets.doe.gov**.

DOE's *Fleet Buyer's Guide* includes a summary of federal tax credits, deductions, and incentive programs sponsored by DOE, EPA, the Federal Highway Administration within the U.S. Department of Transportation (DOT), and many states, which offer a variety of incentives to encourage fleets to switch to AFVs. The on-line version of the *Fleet Buyer's Guide* allows state-by-state searches to identify incentives available from each state and related contacts for further information. The guide describes what AFVs are available, identifies where fueling stations are located, and provides the cost differences between using AFVs and conventional vehicles.

Another key source of information about incentives is a report released in February 2001 by the National Conference of State Legislatures (NCSL), entitled *State Alternative Fuel Vehicle Incentives, A Decade and More of Lessons Learned.* NCSL is a bipartisan organization serving legislators and their staffs in all 50 states and territories. NCSL's objectives are to improve the quality and effectiveness of state legislatures, foster interstate communication and cooperation, and ensure the states' strong cohesive voice in the federal system. The report is essentially a survey of Clean Cities coordinators and representatives from utility companies, government officials, manufacturers, and fleet representatives. There were 305 responses to the survey, 20 percent of those contacted. The report can be found in PDF format at the Alternative Fuels Data

Center by searching for NCSL and can be purchased on the NCSL web site (http://www.ncsl.org/public/catalog/catdir.htm, then click on Public User and either click Transportation and scroll down or search for the title).

Many funding programs from the federal and state programs require a calculation of air quality savings based on using the alternative fuel vehicles. These savings would be based on the engine certification emissions levels from the EPA (www.epa.gov/otaq/certdata.htm) or California Air Resources Board (CARB) compared to the emissions levels provided in Table 2-1. These emissions savings calculations are described on the Moyer program web site at CARB – arbis.arb.ca.gov/msprog/moyer/moyer.htm.

The combined result of federal and state programs is that the air is becoming cleaner and both government and private sector fleets are expected to comply with required future emission regulations, which are expected to be much stricter beginning in 2007. Future legislated incentives may be significant, assuming they are approved. The current push by the natural gas and electric vehicle industries includes a 50-cents-per-gallon incentive for using alternative fuels. Descriptions of current and potential future incentive programs can be found on several web sites, including:

- U.S. Department of Energy, Alternative Fuels Data Center: www.afdc.doe.gov
- U.S. Department of Energy, Clean Cities Program: www.ccities.doe.gov
- Natural Gas Vehicle Coalition: www.ngvc.org
- U.S. Environmental Protection Agency retrofit program: www.epa.gov/otaq/retrofit
- California Energy Commission: www.energy.ca.gov/afvs/
- California Air Resources Board, Moyer Program: arbis.arb.ca.gov/msprog/moyer/moyer.htm
- Calstart – Westart organization: www.calstart.org/fleets.

What Is LNG?

Before entering into the details of effectively operating LNG vehicles, some background information about natural gas, LNG, and their use as vehicle fuels is appropriate. Natural gas is abundant domestically and is used to heat homes and cook food throughout the U.S. Currently, there are over a million natural gas vehicles on the road worldwide[9], and more new natural gas-powered vehicles are being produced every year. While most of these vehicles operate on compressed natural gas (CNG), the use of LNG vehicles is growing. Natural gas is a clean burning alternative transportation fuel available in adequate quantities today. It is composed primarily of methane (more than 85 percent) and other hydrocarbon gases, such as ethane, propane, butane, and pentane, as well as gases such as nitrogen and carbon dioxide.

[9] Natural Gas Vehicle Coalition web site: www.ngvc.org accessed 12/12/01.

Natural Gas Characteristics

Natural gas is available throughout the world, produced from wells or reservoirs of pure natural gas or petroleum with natural gas. These wells may contain other liquids and materials. Most petroleum wells contain a considerable amount of natural gas. When energy exploration companies drill a well, the natural gas may be captured for processing and sale, for re-injection into the well after petroleum and/or other chemicals are removed, or the natural gas may be flared (burned) or vented on-site.

In addition to conventional sources of natural gas, there also are non-conventional sources of natural gas. Many of the largest deposits of natural gas are in locations that are not accessible for large-scale sale and distribution. These deposits are called stranded gas reserves. Other natural gas sources include hydrated natural gas deposits in the oceans and natural gas from landfills. Hydrated natural gas is trapped within a lattice of water molecules in an ice-like form. Landfill gas can be recovered from existing landfills, but has a low methane content and a high concentration of carbon dioxide and other materials. The methods for retrieving these non-conventional sources of natural gas are still under development and are not yet commercially viable. However, if these sources, especially hydrates, could be accessed, the impact on the supply of natural gas would be substantial. The Department of Energy's Office of Fossil Energy notes that the recovery of one percent of the potential domestic hydrate resources would more than double the domestic gas resource base.[10]

After considering the existing and potential sources of natural gas, we should look at how natural gas is processed and distributed. After retrieval of conventional natural gas, processing is required to separate the natural gas from other liquids and contaminants. First, the gas is separated from free liquids such as crude oil, hydrocarbon condensate, water, and solids. The separated gas is then further processed to meet specified requirements for natural gas transmission companies. Natural gas is distributed throughout the United States via extensive pipeline systems from the well to the end user. The system consists of long-distance transmission pipelines, followed by local distribution systems. Some high-pressure and liquefied storage is also used to help meet seasonal peak demands.

Natural gas is colorless and odorless, but odorants are typically added to gaseous forms of natural gas to aid in leak detection. Conventional odorants solidify at temperatures higher than those necessary to liquefy natural gas. For this reason, LNG typically does not contain odorant. The same liquefying process that prevents the use of odorants, serves to purify the natural gas fuel, meaning that LNG contains significantly fewer contaminants than pipeline natural gas, from which CNG is typically derived. A comparison of fuel composition of natural gas sources, as reported in the results of a GRI survey, is shown in Table 2-2.

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[10] Energy Information Administration, Natural Gas 1998: Issues and Trends, April 1999.

Table 2-2. Average Natural Gas Composition in the U.S.

Component	Pipeline Natural Gas	Peak Shaving LNG	LNG from a Nitrogen Rejection Unit
Methane	81.3-97.5%	95.3%	97.5-99.5%
Ethane	2.0-7.0%	4.1%	<1%
Propane	0.27-3.0%	0.43%	<0.1%
Butane	0.04-0.57%	0.08%	
Nitrogen	0.26-10%	0.02%	0.02%
Oxygen	0-10ppm		
Carbon Dioxide	0.47-1.5%		
Water	3.5-20 lb/MMcf		
Sulfur	0-1.2 lb/MMcf		

Source: GRI, "Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States," MVE CD - Liquefied Natural Gas, Alternative Fuel of Choice
ppm – parts per million
MMcf – million cubic feet

Natural Gas as a Vehicle Fuel

Natural gas has proven to be a suitable vehicle fuel and is widely available within the U.S. Natural gas vehicles (NGVs) have been certified to perform in compliance with all current environmental emission standards (e.g., the Clean Air Act Amendments of 1990), including standards limiting PM, non-methane hydrocarbons (NMHC), CO, and NO_x. There is an issue of higher methane emissions from a natural gas vehicle compared to a diesel- or gasoline-fueled vehicle. Methane is considered a greenhouse gas (discussed earlier) and the emissions of extra methane from vehicles is becoming more restricted in many parts of the world.

The major difficulty associated with using natural gas as a vehicle fuel is storing the fuel on-board the vehicle in quantities that will provide comparable ranges to gasoline or diesel vehicles. Two different approaches have been used to reduce the volume of the natural gas needed to fuel the vehicle, compression and liquefaction. When used as a vehicle fuel, compressed natural gas (CNG) is typically stored on board the vehicle at high pressure—up to 3,600 pounds per square inch (psi). When LNG is used as a vehicle fuel, it is typically stored at cryogenic temperatures, which may be as low as -260°F at pressures ranging from atmospheric to 200 psi.

Several private fleets began using CNG in the 1980s. Most of these fleets have their own on-site CNG fueling stations. Since federal incentives began in 1988, the number of NGVs and private and public fueling stations have increased and the use of natural gas vehicles has grown. Most of the growth has been for fleets but the number of individual vehicle owners operating NGVs has also increased. LNG vehicles in the U.S. have only come into significant use since the early 1990's. Still, implementation of LNG vehicles and the experiences of LNG vehicle users are growing.

In general, natural gas engines can be used with CNG or LNG. This is important because while LNG fuel system technologies may only be in their early stages, the natural gas engine technology used on LNG vehicles has been in use over the past two decades.

LNG Background

Liquefying natural gas and other gases began with a desire to liquefy air, mostly to get pure oxygen for use in chemical and metallurgical industrial processes. In the early 1900s, Dr. Karl Von Linde, a German scientist, invented a way to separate air by cooling it in stages under pressure until the various constituents (oxygen, nitrogen) condensed to liquid. Later, this process was used to separate minor components of atmospheric gases such as argon, krypton, and xenon, which were used in the manufacture of light bulbs. Refinements to this process in the 1930s led to the development of the U.S. propane (LPG) industry.

Godfrey Cabot was the first to apply for a patent in the United States to liquefy natural gas. The new process had several benefits. Liquefying natural gas could solve storage and transportation problems by condensing the gas to a liquid, which reduced the storage volume. The LNG could be re-vaporized, returning it to its gaseous state, and sending it through the natural gas pipeline when required to meet high consumption demands, such as during cold winter days. This process of re-vaporizing is known as “peak shaving,” i.e., shaving off the peak demand requirement for the incoming pipeline gas. The first LNG plants in the U.S. for “peak shaving” were built and started operation in the 1940s.

The ability to liquefy natural gas allows large quantities to be stored for seasonal peak shaving or shipped for import/export commodity activities. In the case of stranded gas reserves, natural gas sources not accessible for distribution, the natural gas must be liquefied for transport to market, sales, and distribution. The natural gas may be liquefied directly by cooling the gas to a cryogenic liquid, LNG. Beginning in the 1960s, special shipping vessels were built specifically for the transport of large amounts of LNG. The shipment of LNG required the construction of import and export terminals where LNG could be safely loaded onto the ship and then offloaded for storage.

Another way of liquefying natural gas is to change it chemically to another form that has a higher energy density per volume. The chemical conversion of natural gas to liquid is generally called gas-to-liquid (GTL) and has become an industry of its own. Natural gas may be used to create synthesis gas, which is made up mostly of carbon monoxide and hydrogen. Synthesis gas can be used to make synthetic diesel fuel (using the Fischer-Tropsch process) and other chemical products. These liquids can be shipped by conventional means, rather than cryogenically.

LNG Characteristics

As discussed earlier, the process of liquefying natural gas separates the natural gas from other components by cooling the natural gas in stages under pressure until the constituents of the natural gas are condensed to a clear liquid form. Most LNG is produced at storage locations operated by natural gas suppliers and at cryogenic extraction plants in gas-producing states. Many fleets that depend on heavy-duty vehicles—such as transit buses and trucks—are selecting LNG over CNG because more energy can be stored on board the vehicle in liquid form.

Liquefying natural gas into LNG creates a very compact form of natural gas. One cubic foot of LNG will vaporize into 618 cubic feet of natural gas at atmospheric pressure (618:1). LNG is nearly twice as dense as CNG. This is a major factor in the choice to use LNG in vehicles because it means that more fuel can be stored on board while taking up less space than CNG. This allows LNG vehicles to achieve comparable ranges to their diesel counterparts. It takes 1.55 gallons of LNG to provide the same energy content as a gallon of gasoline and 1.67 gallons of LNG to provide the equivalent energy of a gallon of diesel. For this reason, fuel or efficiency comparisons between LNG and gasoline or diesel are usually made on an equivalent energy basis.

LNG is purified before liquefaction to remove elements possibly transmitted in pipeline gas, such as condensable carbon dioxide and odorants. The condensable carbon dioxide, water, and other elements such as odorant (hydrogen sulfide) from pipeline gas are removed, because they would solidify during the liquefaction process. Then a cryogenic process of refrigeration and/or depressurization is used to liquefy natural gas. This process removes some of the heavier hydrocarbons, leaving mostly methane (85 to 99 percent). The resulting LNG is a clear and odorless liquid that is non-toxic, non-corrosive, and non-carcinogenic. Because of the purification process, which separates LNG from potential contaminants, natural gas fuel derived from LNG is much purer than pipeline natural gas (See Table 2-2).

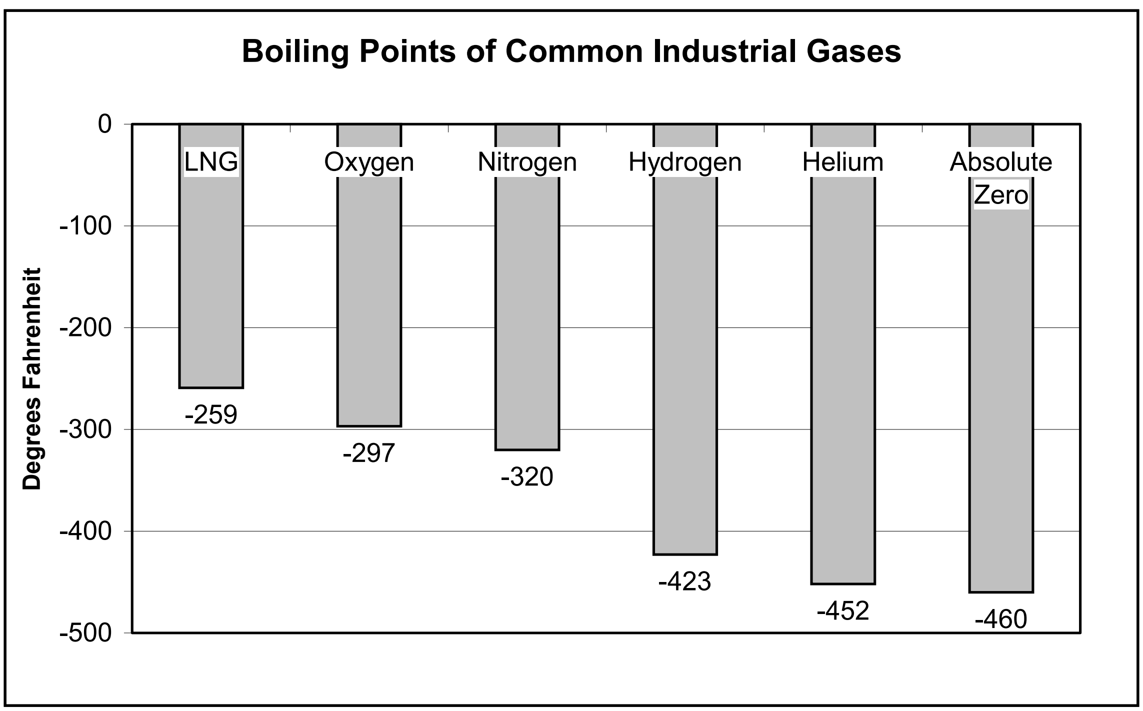

Figure 2-3. Boiling Points of Industrial Gases at Atmospheric Pressure

LNG can be produced at a variety of chemical processing facilities, including: an LNG plant, where heavier hydrocarbons and carbon dioxide in the natural gas are removed; nitrogen rejection units (NRU), which remove nitrogen from natural gas; LNG import/export terminals; facilities where peak shaving is conducted; and other prototypes or experimental plants such as landfills, or synthesis gas and olefin plants. (For additional information on sources of LNG, see the subsection titled **Is LNG Readily Available?**)

The LNG purification and refrigeration process is not unique. Industrial gases, such as nitrogen, oxygen, and helium, are used in manufacturing, food processing, and hospital operations on a regular basis. These gases are transported as cryogenic liquids to maximize the loads that trucks can carry. As shown in Figure 2-3, several of these cryogenic products have a lower boiling point than LNG. However, all cryogenic liquids are very cold, and special procedures and training are required to handle them. While cryogenic liquids require special attention, there is extensive experience handling cryogenic liquids in the industrial gas industry. The industrial gas industry produces and transports cryogenic liquids on a daily basis, and LNG users can learn from their experience.

Table 2-3 compares the chemical properties of LNG with those of other fuels. Natural gas ignition requires mixtures in the 5- to 15-percent range. This flammability range is actually wider than some fuels, but since natural gas is lighter than air, it is likely to dissipate quickly. This makes LNG less likely than other fuels to ignite in an open environment. Spills of LNG will rapidly dissipate (rise) in the atmosphere as natural gas, which is buoyant at temperatures above -160°F. However, released natural gas will rise and can be trapped in ceiling pockets.

The properties shown in the table below are described in the following definitions. There are many other properties that could describe these fuels, only a few were chosen here.

Boiling Temperature – The temperature at which a liquid boils. This temperature is usually given at atmospheric pressure (0 psig). Pure methane boils at –259 °F at 0 psig. The boiling temperature increases as the pressure increases. At 100 psi, pure methane has a boiling temperature of about –200 °F.

BTU (British Thermal Unit) – A BTU is a measure of heat energy used to describe the heat released upon combustion of any substance. BTU is the quantity of heat energy that must be added to one pound of pure water to raise its temperature one degree F.

Fuel Density – The mass of fuel per volume. Fuel density and fuel energy density are directly related. As the fuel density increases, the fuel energy density increases.

Autoignition Temperature – The lowest temperature at which a substance will ignite without having an external ignition source. At this temperature, ignition can occur from heat alone and not from a spark or flame. Pure methane has an autoignition temperature of 1202 °F.

Flammability Range – A substance or fuel requires the proper mixture with air to burn. The flammability range describes a range of volume percent of fuel in air in which burning can occur. Below the lower limit of the flammability range (lower flammability limit – LFL), there is not enough fuel to burn. Above the higher limit of the flammability range, there is not enough air to support combustion.

Lower Heating Value – The amount of energy contained in the fuel. Fuel heating values are usually described as higher heating values (HHV) or lower heating values (LHV). The difference between HHV and LHV depends on whether or not the latent heat of vaporization of the water formed from combustion of the fuel is included. If the latent heat of vaporization of water is included, then the HHV or gross heating value is used. If the water formed from combustion is not included, then the LHV or net heating value is used. In transportation in the U.S., the LHV is generally used and is shown in the table on a mass and volume basis.

Source of definitions:

Murphy, M.J., 2000, "Motor Vehicle Fuels: Properties and Specifications", Battelle.

Murphy, M.J., 1994, "Properties of Alternative Fuels, Federal Transit Administration", FTA-OH-06-0060-94-1.

GRI/SAIC, 1992, "Introduction to LNG Vehicle Safety", GRI-92/0645.

Table 2-3. Chemical Properties of Natural Gas and Other Fuels

Property	Pure Methane	LNG	CNG	LPG	Diesel	Gasoline
Formula of the major chemical component(s)	CH_4	CH_4	CH_4	C_3H_8	C_3 to C_{25}	C_4 to C_{12}
Boiling Temperature, °F	-259	-259	-259	-44	370-650	80-437
Fuel Density @ 60°F [excluding RLM, LNG] (lb/gal)	1.07 (at atmospheric pressure) RLM: 3.54	3.53	1.58 (at 3500 psi)	4.22	6.7-7.4	6.0-6.5
Autoignition Temperature, °F	1202	1004	1004	850-950	600	495
Flammability Range, vol.	5% - 15%	5% - 15%	5% - 15%	2.2% - 9.5%	1% - 6%	1.4% - 7.6%
Lower Heating Value (BTU/lb)	21500	20200-21500	20200-21500	19800	18000-19000	18000-19000
Lower Heating Value (BTU/gal)	23005 RLM: 76100	72700-77400	31900-33800	84500	128400	115000
Specific Gravity @ 60°F	0.129 (at atmospheric pressure) RLM: 0.428	0.435	0.192	0.508	0.81-0.89	0.72-0.78

RLM – Refrigerated liquid methane
Source: Alternative Fuel Data Center, ALT, and Battelle

Methane Number – There is one more topic of interest on describing a fuel for use in an engine – motor octane number and methane number. These two numbers are used to describe the tendency for a fuel to knock (early or pre-ignition) in a spark-ignited engine. Motor octane number is most likely familiar based on ratings used for gasoline used in light-duty vehicles. Methane number has been developed to better describe knock tendency of gaseous fuels like natural gas. "The motor octane numbers were determined using a procedure (from ASTM), which uses isooctane and n-heptane as the reference fuels, where 100% isooctane equals 100 octane number and 100% n-heptane equals 0 octane number. The methane number scale is based on the molar percents of methane and hydrogen, with neat methane equal to 100 methane number."[11] In both cases, the higher the octane and methane numbers the better expected knock performance (or less knock tendency) of the fuel.

This discussion on methane number is important because specifications of fuel quality required for spark-ignited natural gas engines are many times based on methane number. Recently, there has been a push to reduce the methane content requirement for LNG so that more supply can be used in transportation. Currently, most LNG vehicle users require very high methane content (>98%). This higher methane content for LNG is intended to reduce the effects of weathering of the fuel. With more potential sources of LNG for vehicle use being made available, there is a need to relax this methane content to one that is more similar to the CNG methane content level, which is usually around 85% methane content or more. The lower methane content can also lower the price of the LNG. Current requirement for Cummins and DDC natural gas engines is around a methane number of 65 or better/higher. Your LNG supplier can provide the methane number for LNG fuel that they can supply. Note that the lower the methane content, the more vigilant that users will need to be in understanding weathering of LNG and minimizing the effect. LNG weathering is discussed in more detail later in this subsection.

Resources:

Ryan, T., Callahan, T., Effects of Gas Composition on Engine Performance and Emissions, GRI-91/0054, 1991.
Kubesh, J., King, S., Liss, W., Effect of Gas Composition on Octane Number of Natural Gas Fuels, SAE-922359, 1992.
Liss, W., Thrasher, W., Natural Gas as a Stationary Engine and Vehicular Fuel, SAE-912364, 1991.

LNG Saturation

Saturation is one of the most difficult concepts associated with LNG vehicle operations. Saturated substances often behave opposite of what one might expect. Unlike gases, which increase in density under higher pressures, saturated liquid-vapor mixtures are less dense at higher pressures. Understanding saturation is critical to assessing the use of LNG and the amount of LNG stored on a vehicle or in a storage tank. Without understanding saturation and pressure issues, fuel storage systems can appear to "create LNG" because more higher-pressure gallons are dispensed to the vehicles than the number of gallons delivered to the storage tanks at near ambient pressures. The higher-pressure gallons are less dense and contain less actual fuel energy than the lower-pressure gallons. The following discussion of saturation should help to clarify the confusing saturation issues.

LNG is stored on-board a vehicle as a saturated liquid-vapor mixture. This means that the mixture is in between the liquid and vapor phases, so it will boil when heat is added and condense when heat is removed. To understand LNG saturation, it is helpful to briefly consider the process of refrigerating natural gas to make LNG. As heat is removed from the gas, its temperature decreases. This continues until the gas becomes so cold that it begins to condense to a liquid. The temperature and pressure at which this occurs is called the saturation point. Both

[11] Southwest Research Institute, Effects of Gas Composition on Engine Performance and Emissions, GRI-91/0054, 1991.

the gas (which is usually referred to as a vapor in this state) and the liquid that starts to form are said to be saturated. At this point, removing heat will cause more vapor to condense to liquid, but will not reduce the temperature as long as the pressure is held constant and the natural gas is not completely condensed, or liquefied. The temperature at which this transition from vapor to liquid takes place is called the saturation temperature.

In commercially available LNG fuel systems, fuel is stored on-board vehicles under saturated conditions, because it reaches an equilibrium of liquid and vapor through boiling and condensation. As stated earlier, a saturated liquid-vapor mixture typically boils when heat is added and condenses when heat is removed. The example of boiling water in a teakettle or pressure cooker is often used to explain saturation. It is well known that water boils at 212°F (100°C) at atmospheric pressure. But, at higher pressures, water must be heated to a higher temperature before it begins to boil (this is why a “pressure cap” is used on automobile cooling system radiators, forcing the pressure in the radiator to increase before the cap allows the coolant to overflow into the coolant reservoir). The saturation temperature increases as the pressure increases. Water already at a high temperature can also be made to boil by decreasing its pressure (vapor generation in this fashion is sometimes called flashing). The pressure at which the water starts to boil is the saturation pressure.

The same is true for natural gas as it is for water. The saturation temperature for condensation or boiling depends on the pressure. Conversely, the saturation pressure for boiling or condensation depends on the temperature. The relation between saturation temperature and saturation pressure is shown in Figure 2-4. This is known as the saturation curve or saturation line.

Figure 2-4 applies if the natural gas (and LNG) is 100% methane. When natural gas contains other constituents, the saturation temperature (or pressure) changes slightly as more vapor is condensed to liquid, or liquid is boiled to vapor. Also, the concentration of non-methane constituents is different in the liquid and vapor phases. If the non-methane constituents have a higher boiling temperature than methane, they may be more concentrated in the liquid phase. This phenomenon is called “weathering” or “enrichment” in some situations.

When natural gas is saturated, the liquid phase usually has a much higher density than the vapor phase. The dependence of this density on the pressure and temperature is indicated in Figures 2-5 and 2-6, by the difference in density between the triangle to the far right of the figures and the circle to the left of the figures. It should be noted that these points lie on the broken-line curves labeled “saturation line.”

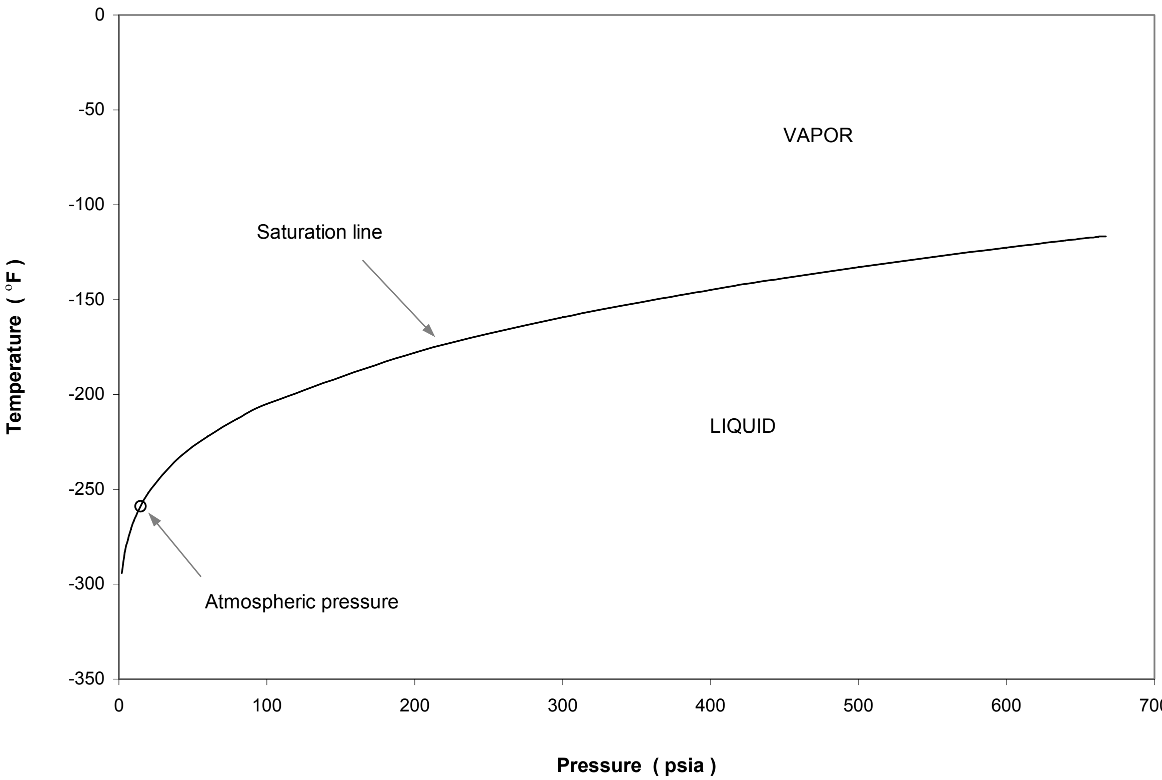

Figure 2-4. The Saturation Curve for Natural Gas (100% methane), Defines the Conditions Where the Liquid and Vapor Phases Can Coexist (Note: °F = 1.8°C + 32, 1 psi = 6.90 kPa).

In Figures 2-5 and 2-6, the triangles to the right denote the state of the liquid in the LNG fuel tank, which is assumed to be saturated at a typical pressure of 100 psig (690 kPa). The corresponding saturation temperature is -200°F (-93°C). Note that the liquid density at this state is 23.0 lbm/ft^3 (368 kg/m^3), which is nearly twice the density of a full CNG fuel tank. The higher density of LNG relative to CNG is the main reason that LNG is preferred for many heavy-duty vehicles with high fuel consumption and limited space for fuel tanks. On the other hand, CNG is more convenient for light-duty vehicles and many medium-duty vehicles, because fueling is simpler and there are no issues associated with cryogenic materials, fuel vaporization, and venting.

The circles on the left side of Figures 2-5 and 2-6 denote the state of the vapor in the LNG fuel tank ullage, which is saturated at the same temperature and pressure as the liquid. As discussed under the heading **Normal Vehicle Operations** later in this subsection, this vapor is fed to the engine when the economizer valve opens to reduce the LNG fuel tank pressure.

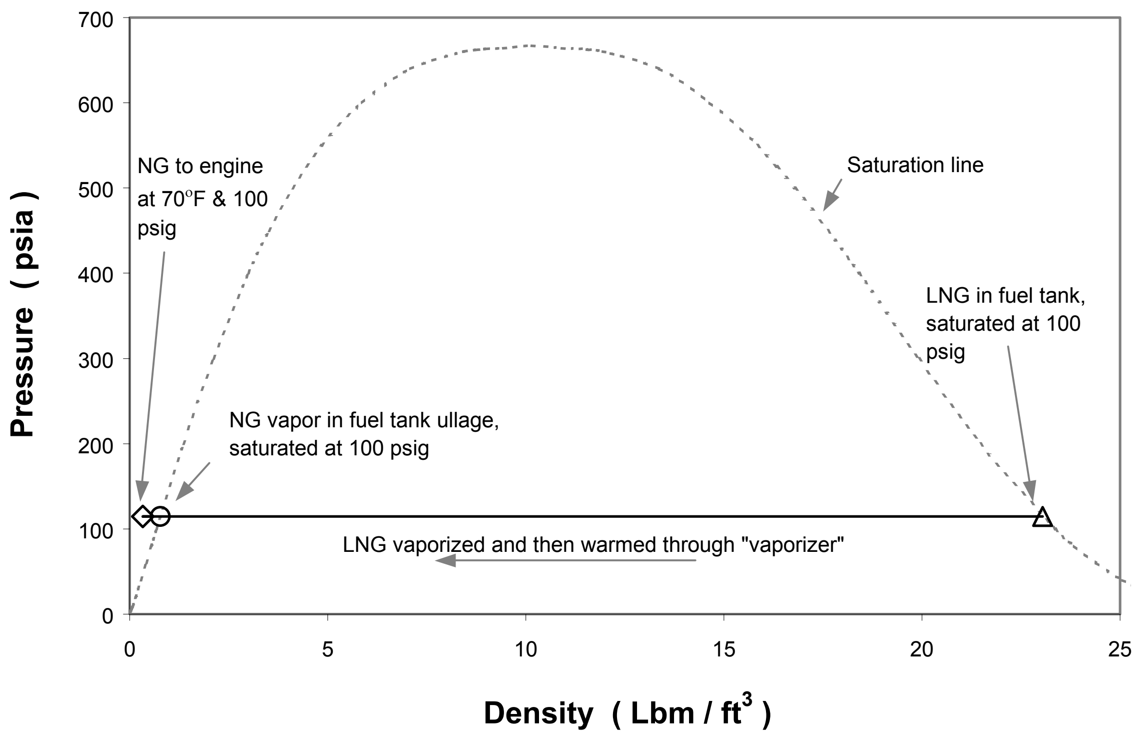

Figure 2-5. Pressure-Density Conditions of LNG Fuel Systems

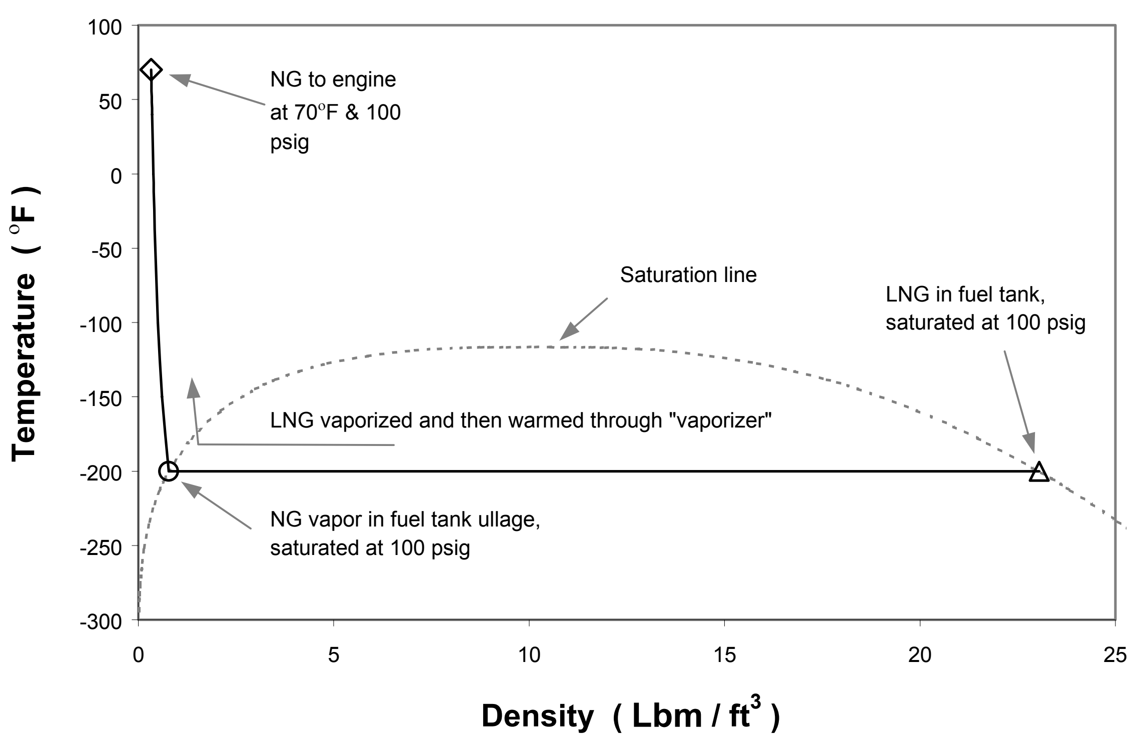

Figure 2-6. Temperature-Density Conditions of LNG Fuel Systems

The path shown from the triangle to the circle to the diamond in Figures 2-5 and 2-6 denotes the change experienced by the LNG as it is warms in the vaporizer. Its temperature and pressure remain constant at saturation conditions until all the liquid is boiled to vapor. As more heat is added in the "vaporizer," the gas temperature increases (Figure 2-6), and the density decreases slightly.

Figures 2-5 and 2-6 illustrate an additional issue pertaining to LNG fuel system design. Note that if the LNG could be stored at a lower saturation temperature and pressure, its density would be greater and so more fuel could be stored in a given-size fuel tank. However, for current-generation LNG fuel systems, it is convenient to store LNG at a saturation pressure slightly more than the engine fuel pressure requirement. This simplifies the system because no fuel pump is required, but it also involves compromises including the quantity of fuel that can be contained in the fuel tank.

LNG Vehicles

A basic description of LNG vehicles can help to understand the issues involved with vehicle operation and maintenance. In many ways, LNG vehicles operate in the same manner as conventional vehicles. Both types of vehicles operate using an internal combustion engine and are driven in the same manner. The major difference between LNG vehicles and conventional vehicles is the LNG fuel system, which accepts and stores cryogenic fuel, warms and regulates the fuel, and delivers the fuel to the engine in gaseous form. In the text that follows, a basic LNG fuel system, its components, and its operation are discussed. The fuel system considered here is of a general nature and based on the Chart/NexGen Fueling LNG fuel tank design. Some aspects of this fuel system design may not be directly applicable to the vehicles you are operating or considering. It is important to understand the operation of your specific vehicles. This basic fuel system description is intended to provide the framework from which to build an understanding of the operation of the vehicles in your fleet. Figures 2-7 and 2-8 show LNG vehicles at Raley's in Sacramento, California.

Fueling Operations – Most LNG vehicle fuel tanks are filled through a single hose and connection as illustrated in Figure 2-9. Although the details of the LNG fueling operation may be complex, they are automated such that the fuel hostler connects the fill hose to the fill connector and then activates the fueling cycle at the fueling station. The fueling station pumps LNG, which is typically at approximately 100 psi (690 kPa) and -200°F (-129°C), into the vehicle fuel tank(s). The fuel flows into the fuel connection and through the check valve, which only allows flow in a single direction, preventing the return of fuel to the fueling station. The liquid fuel is sprayed into the fuel tank through the fill spray header and into the vapor region in the fuel tank. The cooler liquid spray condenses (or "collapses") the vapor so that the tank pressure does not increase as it is filled with liquid. The LNG tank is not to be filled completely. There is an ullage space, which allows for the expansion of the liquid as it heats up in the tank.

Figure 2-7. LNG Trucks at Raley's in Sacramento, California

Figure 2-8. LNG Yard Tractor at Raley's in Sacramento, California

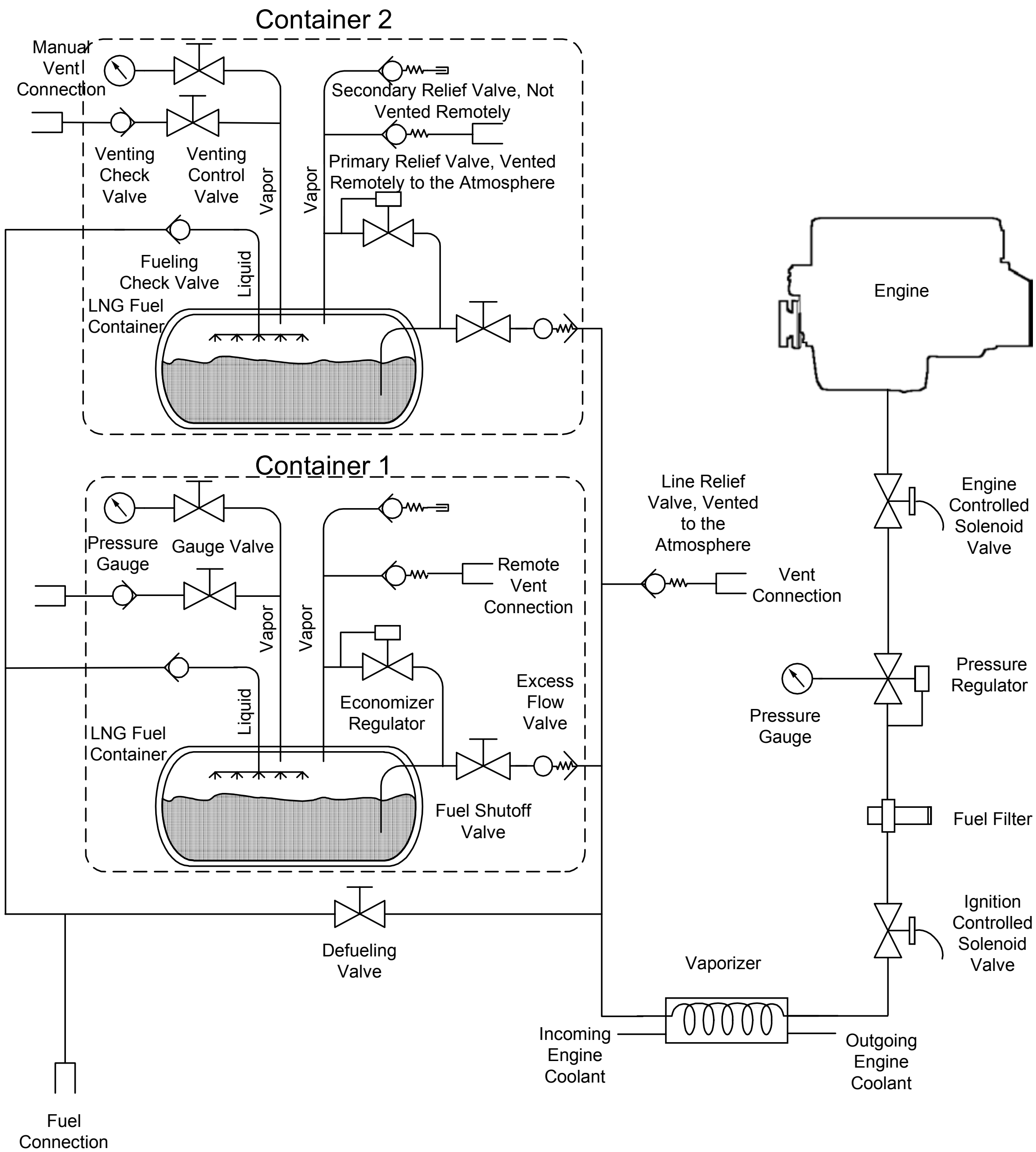

Figure 2-9. LNG Fuel System

If the LNG fuel tank pressure is near its maximum level prior to fueling (e.g., because the vehicle has not been driven for a few days; see the heading **Normal Vehicle Operation** below), the fueling station pump may be unable to overcome the pressure difference between the vehicle and station LNG tanks. In this case, a vent hose is connected to the manual vent connection, and the venting control valve is opened. Vapor then flows from the vehicle tank back to the station, the vehicle fuel tank pressure decreases, and the fueling operation can proceed. The fuel tanks stop filling automatically when the liquid fuel covers the spray header and the pressure rises.

Normal Vehicle Operation – During vehicle operation, the fuel tanks supply liquid natural gas to the vaporizer heat exchanger where it is vaporized and warmed by engine heat from the engine coolant lines. The pressure in the vaporizer is approximately the same as that supplied by the fuel tanks. The gaseous fuel, which is at near-ambient temperature as it exits the vaporizer, is then filtered and regulated to final pressure before delivery to the engine. The fuel filter and pressure regulator can be seen in Figure 2-10. In typical operation, when the fuel is at normal pressures, the fuel tanks supply liquid from the bottom of the tanks. When the vehicle is parked for a period of time, heat slowly entering the fuel tanks vaporizes some of the fuel and increases the fuel pressure. Upon starting after an idle period, elevated pressure in the tank will open the economizer valve on the fuel tank. This valve releases gas from the tank into the fuel stream, drawing down the tank pressure to the economizer set pressure. As long as the LNG vehicle is operating on a regular basis (operating at least every 3 days), the LNG fuel tanks should not vent natural gas to relieve pressure.

Defueling Liquid from the Fuel Tanks – To perform maintenance on the LNG fuel systems, often the fuel tanks must be defueled. Most LNG fuel systems can be designed to defuel liquid through the fill connector, although a separate connector may be used. Similar to fueling, the fuel hostler connects the fill hose to the fill connector and activates the automated defueling process on the fuel station. The system uses the differential pressure between the vehicle fuel tanks and the fuel station bulk storage tanks to “push” the liquid from one to the other. This process is intended to remove all of the liquid (though not the vapor) from the tanks, when the fuel pressure in the bulk storage tanks is adequately below the vehicle fuel tank pressure.

Venting Vapor from the Fuel Tanks – When necessary, LNG fuel systems are designed to vent vapor and excess pressure from the fuel tanks through a vent connector. Vapor may be vented back to the fueling station bulk storage tanks or it may be vented to atmosphere.

Pressure Relief – The fuel tanks used on LNG vehicles are specially designed to insulate the fuel and keep its temperature as low as possible for as long as possible. However, over time, heat slowly enters the fuel tank, vaporizing some of the fuel and increasing the pressure in the tank. As explained earlier in **Normal Vehicle Operations**, if the vehicle is operated regularly, the economizer valve will relieve pressure build up in the tank by allowing fuel vapor to enter the fuel stream as it heads towards the engine. Yet, if the vehicle is parked for an extended period of time, the pressure in the tanks could continue to increase indefinitely. For this reason, fuel tanks are equipped with pressure relief valves that are set to open and relieve pressure in the fuel tanks well before the pressure reaches dangerous levels, such as a pressure that can rupture the tank.

After relieving pressure, pressure relief valves are designed to reclose when the pressure in the tank decreases. Typically, fuel tanks are designed with a primary relief valve that releases fuel through vent piping routed to the roof of the vehicle and away from passenger compartments. For added reliability, LNG fuel tanks generally have a secondary relief valve, set to open at a pressure higher than the set pressure of the primary relief valve, yet well before the pressure in the tank reaches dangerous levels. This secondary relief valve is designed to activate if the primary relief valve fails to maintain the tank below a set pressure. The secondary relief valve in an LNG system is typically not piped away to a vent because one of the possible reasons for failure of the primary relief valve is the vent line leading from the primary relief valve has become blocked.

Line relief valves are also employed in the fuel system in places where liquid fuel might be trapped between valves and vaporize. Vaporization of trapped liquid fuel can increase pressure dramatically and cause component rupture. Line relief valves are designed to activate before pressure within fuel lines reaches damaging levels. The line relief valves are typically vented to the atmosphere.

Figure 2-10 provides a 3-dimensional schematic of the same basic LNG fuel system setup shown in Figure 2-9. This is intended to give the reader an idea of what the basic components of an LNG fuel system look like and how they function together.

Other LNG Fuel System Designs – Figures 2-9 and 2-10, and the preceding text, apply to the most commonly used LNG fuel system design. This type of fuel system is used on nearly all the LNG-fueled trucks and buses currently operating in the U.S. However, a number of different LNG fuel system designs are under development, and some are being field-tested. For example, one variation on the previously described LNG fuel system is designed to operate at lower maximum fuel pressures. It seeks to employ a more highly insulated tank design to reduce heat transfer to the fuel. In this design, only liquid (i.e., not vapor) flows out of the fuel tank, and a special circuit is employed to increase fuel pressure if it is below the level required by the engine. Another example of a different LNG fuel system design is the one used for vehicles with natural gas engines employing high-pressure direct injection technology. These fuel systems include a hydraulically driven reciprocating pump to increase the LNG fuel pressure to over 3,000 psi (20.7 MPa). This pressure is needed for direct injection into the combustion chamber. The design approaches for pump placement, pump priming, vapor management, and other fuel system features are still evolving.

LNG Fueling Stations

In addition to understanding LNG vehicles, it is also helpful to understand the operation of LNG fueling stations. In the earlier discussion of LNG vehicles, it was noted that it is important to understand the specific design used in your application, because there are variation in designs. This is even more of an issue with fueling stations. The following text explains the elements of a basic LNG fueling station. The actual station or stations you are using or considering may or may not incorporate all of the elements discussed here. The station your fleet uses will typically be significantly more complex than the basic LNG fueling station shown in Figure 2-11. Figure 2-12 shows an actual LNG fueling station at Raley's in Sacramento, California, and Figure 2-13 shows an LNG fueling station at the City of Tempe, Arizona. Like the previous discussion of LNG vehicles, this overview of the elements of LNG fueling stations is intended to provide the basic framework from which to build your understanding of the station or stations you are using or considering.

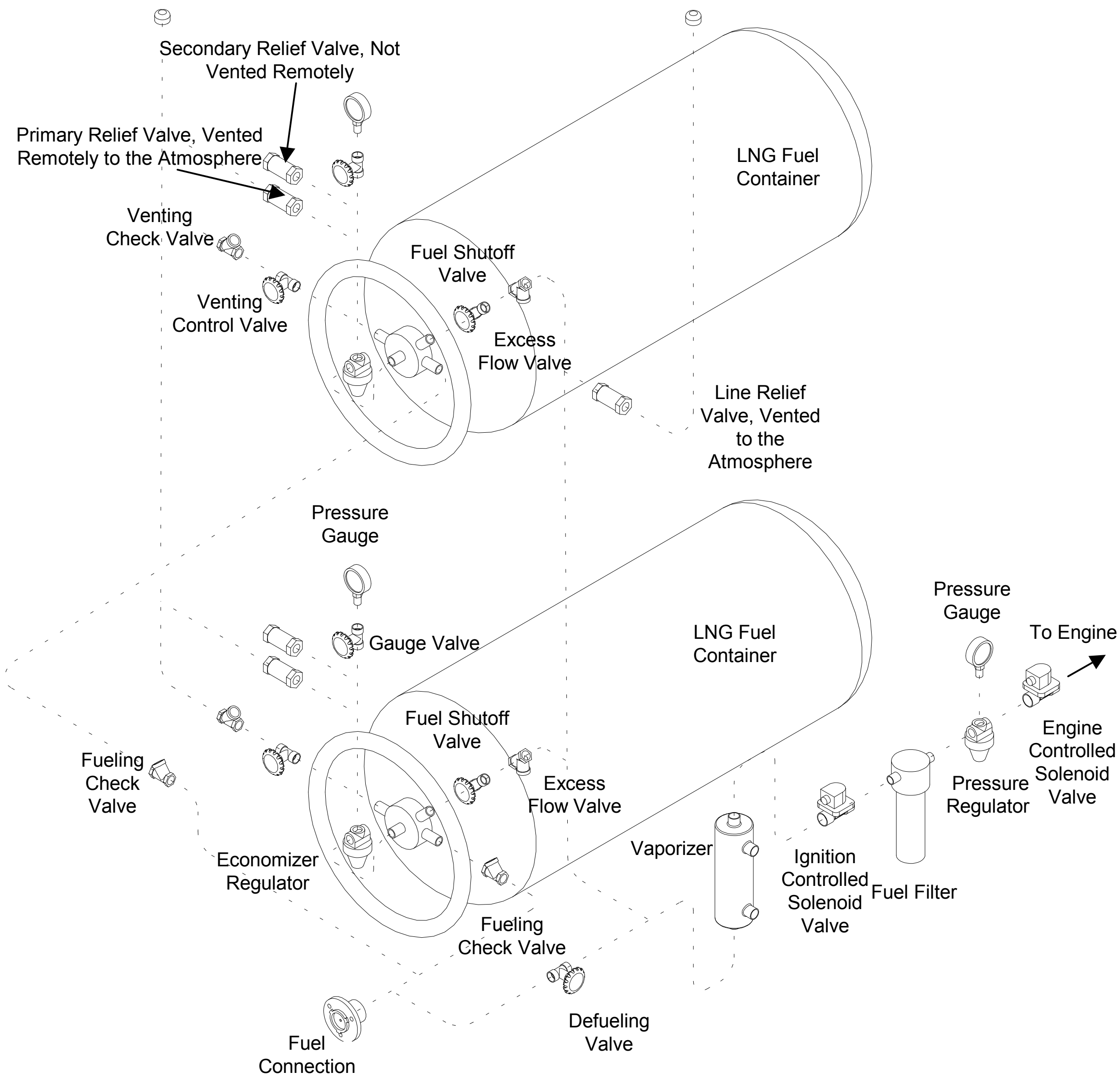

Figure 2-10. LNG Fuel System Schematic

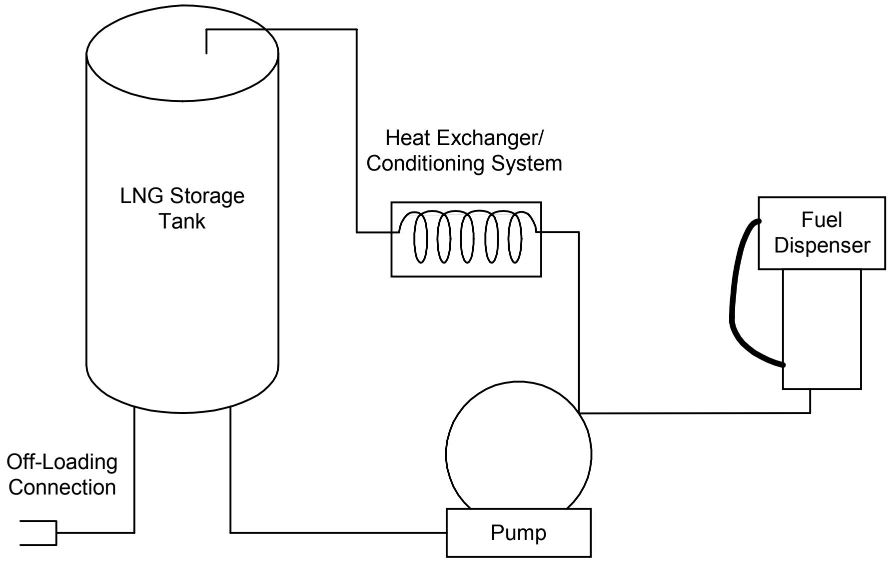

Figure 2-11. Simplified LNG Fueling Station

Figure 2-12. LNG Fueling Station at Raley's in Sacramento, California

Figure 2-13. LNG Fueling Station at City of Tempe, Arizona

Fuel Storage – LNG can be stored above or below ground at fueling stations in highly insulated tanks that are larger and heavier than diesel fuel tanks. The tanks are double-walled with efficient insulation between the walls. They can be sized to meet your fleet's needs, but a tank of 13,000 gallons is often chosen because of its ability to accept a typical 10,000-gallon tanker truck delivery of LNG.

Large users of LNG fuel may typically have up to 100,000 gallons of LNG on-site. Typical bulk storage tanks for LNG are in nominal sizes of 15,000, 20,000, and 30,000 gallons each. Large bulk fuel storage tanks have a low aspect ratio—height to width—and are cylindrical in design with a domed roof. The bulk storage tanks are vacuum-jacketed, pressure vessels. These tanks may be at pressures anywhere from 50 psi to more than 250 psi. At some sites, LNG is stored in below-ground storage tanks, using the soil to protect the tank from high ambient air temperatures; reducing vapor dispersion and the physical space requirements; and minimizing the potential for vandalism or vehicles colliding with the tank. Above-ground LNG fueling installations usually require a partially below-grade dike to control LNG flow in the case of a catastrophic LNG spill from the bulk storage tank.

Stored LNG must be kept cold (between -260°F and -117°F, depending on pressure) to remain a liquid. The lower the temperature of LNG in the fuel storage tanks, the lower the vapor pressure within the tank, the more dense the fuel, and the more fuel energy can be moved to the vehicle's on-board fuel tanks, thus the greater range the vehicle will have.

Fuel Transfer – A pump is generally necessary to overcome the pressure inside the vehicle fuel tanks. In many cases, due to the pump heat, fuel vapor or low-density liquid fuel is piped back to the storage tank. Pressure transfer and gravity transfer have also been used to move the fuel from the storage tanks onto the vehicle.

Heat Exchanger/Conditioning System – A heat exchanger/conditioning system is used on most LNG fueling stations. This system is designed to ensure that the fuel is saturated at the proper pressure before delivery to the vehicle. It uses the heat from the ambient air or another source to heat the fuel. Depending on the fuel station design, this conditioning of the fuel may be done for the entire bulk fuel storage, for a separate and smaller storage tank at the station, or with a heater when delivering fuel to a vehicle (on-the-fly conditioning).

Fuel Dispenser – The fueling equipment is similar to the pump and hose used for gasoline or diesel dispensing. The major difference is the dispensing nozzle size and locking requirement to ensure a proper seal to avoid leaks or spills. LNG dispenser hoses are also vacuum jacketed for insulation. Fueling dispensers are typically equipped with metering devices to measure the fuel dispensed (liquid and vapor), and displays the amount of fuel dispensed. The fueling connection on the fueling dispenser must be compatible with the connection on the vehicle. A typical fuel dispenser is shown in Figure 2-14 and the fueling port on a transit bus is shown in Figure 2-15.

Figure 2-14. LNG Fuel Dispenser at OCTA in Garden Grove, California

Figure 2-15. LNG Fueling Port on a Transit Bus

Gas and Fire Detection and Remediation – Fueling stations also may be equipped with systems which detect fire or gas releases and implement remediation strategies. These types of systems are often used on LNG installations because LNG is not odorized to enhance detection of gas releases.

Venting Systems – Not shown in the simplified fueling station shown in Figure 2-11 is the venting system for the fueling station. The venting system will allow fuel vapor to escape before the pressure in the storage tank reaches dangerous levels. This system should also be designed to accept vented gas from the LNG vehicles at the station.

Control Panel and Additional Instrumentation – Fueling stations may also be equipped with a control panel and other instrumentation. Instruments to measure the temperature and pressure in key areas of the fueling station can aid problem diagnosis.

Vehicle Fueling – Fueling stations can be designed to make fueling LNG vehicles very similar to fueling conventional vehicles. The fueling operation typically consists of connecting the fueling nozzle to the vehicle and activating the fueling dispenser. Vehicles can typically be fueled in around five minutes.

Resources:
Chart LNG Training School Course Materials
Best Available Practices for LNG Fueling of Fleet Vehicles, GRI-96/0180, 1996

Weathering of LNG Fuel

While LNG consists primarily of methane, it also contains fractions of ethane, propane, small amounts of higher hydrocarbons, and other heavy liquefied gases. Dedicated natural gas engines are typically designed for a minimum methane content in the fuel. When the LNG is stored for long periods, there is a tendency for the lighter gases (specifically methane) to boil off and vent, leaving the heavier components. Consequently, the methane content of fuel that is stored for long periods of time can diminish. This process is known as weathering or enrichment. The potential exists for heavy gases to build up in the fuel within a storage container over time, reducing the methane content of the fuel. This fuel can cause reduced engine performance and even engine failure when used on a vehicle.

In order to reduce weathering, LNG fuel should be treated as a perishable product. Like milk or other perishable goods, over time, the quality of LNG degrades if it is not used. It can be difficult to define an "expiration date" for LNG fuel, but it is important to understand that LNG fuel should not be stored indefinitely for vehicle use.

Proper fleet management is crucial to preventing excessive weathering. The best weapon against weathering is to prevent the fuel being stored long enough for significant boil off. By using the vehicles regularly, the pressure within the fuel containers stays at reasonable levels, preventing excessive vaporization of the fuel within the container, thus preventing weathering. Any techniques that prevent heat gains will also prevent weathering, as well as fuel venting. This is true of both the vehicle fuel system as well as the fueling station. By using the fuel stored on the vehicle and in on-site fuel storage tanks in a timely manner, heat gains are prevented which will reduce both weathering and loss of fuel through venting.

The susceptibility of a vehicle fuel system to weathering will depend on how the fuel system is designed to remove fuel from the fuel tanks. Some systems are designed to remove vapor from the fuel tank before removing liquid. These systems are highly susceptible to weathering because the vapor removed from the tank will be mostly methane. Higher hydrocarbons will become concentrated in the liquid that remains in the fuel tank. As the tank approaches empty, the methane content of the fuel delivered to the engine will decrease. If the tank is not emptied before each refueling, the methane content of the fuel in the tank will progressively decrease with each refueling.

Another system design removes primarily liquid fuel from the fuel tank. While this system will not prevent all weathering, it will prevent progressive weathering of fuel from successive fuelings. With a liquid draw fuel system, there should not be significant on-board weathering issues as long as the vehicles are used regularly. Understanding how the vehicle fuel system used on your vehicles removes fuel from the fuel tanks will help you to properly manage your fleet to prevent excessive weathering. For these same reasons, it is important for you to understand how vapor is managed in stationary fuel storage tanks as well.

A standard fuel content specification for LNG is currently under development. Indications are that these standards will allow reasonably low levels of methane content (less than 90%). While this means that engines designed to this standard may be capable of accepting fuel that has experienced a higher degree of weathering, it also means that LNG may be delivered with lower methane content making it more susceptible to weathering. Under lower methane content standards, there will be an even greater need to be aware of the quality of fuel as it is delivered, and to properly manage fuel usage.

Resources:

Weathering of LNG in On-Board Storage Tanks, GRI-99/0185, 1999.
The Effects of LNG Weathering of Fuel Composition and Vehicle Management Techniques, SAE-952607, 1995.
LNG Weather Effects-Theoretical and Empirical, GRI-92/0464, 1992.

LCNG Characteristics

Liquefied to compressed natural gas (LCNG) is produced by pumping LNG up to a selected pressure level and then vaporizing the liquid through a heat exchanger (vaporizer). LCNG can be used for light- and heavy-duty vehicles and its fueling stations and operations are similar to those for LNG.

It is more efficient and faster to pressurize natural gas when it is in liquid form. LCNG can be pressurized via a relatively small cryogenic pump (e.g., basketball size). Other, more common methods of generating CNG, require a large, expensive multistage compressor at each fueling site. After pressurization and vaporization, the LCNG is odorized, as required for the gaseous form of natural gas. The gaseous fuel is then stored in on-site storage vessels for dispensing or dispensed directly into vehicles. On the vehicle, the high-pressure gas is in cylinders rated for high-pressure. Because of the lower energy density of CNG compared to LNG, more fuel storage space will be required on the vehicles using CNG to provide the same range as with LNG.

Although this *Resource Guide* concentrates on LNG vehicles, fuels, and facilities, understanding the implications of choosing LCNG can be helpful for decision makers. For example, if your fleet operations site is located far from a pipeline (such as at a remote national park) the liquid version of the fuel may be more practical to transport. At the same time, the more established CNG technology may be more readily available, especially if your fleet consists largely of light-duty vehicles. A fleet in this situation could utilize LCNG to take advantage of the higher energy density of LNG for transporting the fuel and the convenience of CNG for storage of fuel on-board the vehicles.

LCNG capabilities can also be added to an LNG fueling station with a modest amount of station modification. With the addition of an LNG pump, a vaporizer, CNG storage tubes (buffer), and a CNG dispenser, an LNG fueling station can be modified to fuel both CNG and LNG vehicles. This option may be ideal for fleets operating both CNG and LNG vehicles. Figure 2-16 shows an LNG fueling station at Waste Management in Washington, Pennsylvania with LCNG equipment and dispenser added.

One issue with LCNG fueling is a lack of lubrication. CNG fuel has more lubrication in the fuel naturally and from the compressor used to create the high pressure (oil carryover). This lack of lubrication of LCNG can be a problem for some natural gas engines, and the user should be careful that LCNG use is acceptable for the engine and the warranty from the OEM.

Figure 2-16. LNG Fueling Station at Waste Management in Washington, Pennsylvania, Station Includes LCNG Capability and Dispenser

Resource:

Czachorski, M., Blazek, C., Kina, R., LNG – CNG Lubricating Oil Delivery System, GRI-97/0387, 1997.

How Do We Get Started?

This subsection presents a general description of what is required for a successful implementation of LNG vehicles. These suggestions will not guarantee success; however, lessons learned from other LNG vehicle operations show that not following some of these suggestions will significantly reduce your probability of success. This subsection focuses on the entire implementation process including early planning, implementation, start-up of operation, and optimization of operation. As a result of other LNG vehicle demonstrations, valuable information has been collected from participating company personnel. Data on operations, maintenance, vehicle performance, and emissions have been collected from many sources and analyzed. The engineers and fleet managers also willingly identified lessons learned from each demonstration. Experience has shown that successful implementation of LNG (or any new technology) in fleet operations is built on planning, strong leadership, and commitment.

One of the major lessons learned from these LNG operations is to have realistic expectations of the implementation process and the costs required for start-up and operation. Implementing any major new technology within a fleet will require additional costs, time, and effort. Planning for this extra effort and cost will be the key to avoiding delays and budget overruns. Although some of these costs can be recovered through incentives, it is rare that any of these projects proves cost-effective during the first few years. Beyond being expensive at start-up, such projects are often slow moving, taking a long time to implement and adjust to the new vehicles and related operations. In short, LNG implementation is not a simple process, and it rarely comes with financial benefits at the beginning, but there are reasons that make LNG implementations worth doing (as discussed earlier in **Why Alternative Fuels?**). Some of the most difficult issues in the beginning come down to the newness of the technology and the lack of information available for making good decisions.

This document is designed to enable you to access LNG information and to give you a basic understanding of the issues associated with planning and implementing LNG vehicles. However, truly examining your fleet's compatibility with LNG will require seeking further information. Many operational aspects of LNG will vary greatly with geographic location as well as fleet type and size. Some major issues that must be examined with respect to your specific needs and location are:

- LNG availability
- LNG fuel cost (especially transportation cost)
- Fuel station capital and operating maintenance costs
- Facility modifications and upgrades required
- Vehicle availability
- Vehicle cost
- Extra vehicle maintenance costs expected
- Codes and regulations in your area
- Available funding, tax credits, and other funding mechanisms
- Other issues described as follows in this subsection

Equipment and Operational Differences with LNG

There are many details about the technical changes involved with implementing LNG vehicle operations that you should be aware of before deciding to implement LNG in your fleet. Only the basic differences are presented in the following text along with additional resources for further information.

In general, when using new technology like LNG, there will be fewer options available. This will apply to engines, vehicle platforms, fuel suppliers, and many other aspects of LNG operation. Using engines as an example, the heavy-duty natural gas engine offerings from OEMs do not have as many of the horsepower and torque settings available that conventional heavy-duty engines do. In addition, this new technology may not perform as well as the conventional systems you have used in the past. Again, using the example of engines, dedicated natural gas engine technology is not as efficient as its diesel counterpart (spark ignition versus compression ignition) especially at low loads and when in idle mode. The natural gas vehicle industry is working on expanding the available options and improving technology performance, but it will take some time for LNG to reach the technological maturity of conventional fuels.

Fuel Differences—As noted earlier, LNG is a cryogenic liquid fuel, which is stored at temperatures as low as -260°F, it has the potential to vaporize and become a combustible gaseous fuel. On average, LNG is less expensive than gasoline or diesel fuel by the gallon. However, LNG generally costs only slightly less than gasoline or diesel on an equivalent energy basis. A gallon of LNG contains less energy content than a gallon of gasoline or diesel. On average, there are only 73,500 British Thermal Units (BTUs) per gallon of LNG, compared with 113,900 BTU/gal for gasoline and 122,700 BTU/gal for diesel. In other words, the LNG energy ratio compared to gasoline is 1 to 1.55, and the LNG energy ratio compared to diesel is 1 to 1.67. LNG is unlike CNG in that the LNG fuel is stored at lower pressure, it is a cryogenic liquid, and it is not odorized. Further information on LNG fuel is contained in an earlier subsection titled, **What is LNG?**

Vehicle Differences—There are several basic differences between LNG vehicles and conventional vehicles. First, LNG vehicles use a more complex fuel system to store cryogenic fuel on the vehicle, to warm and regulate the fuel to proper conditions, and to deliver the fuel to the engine. A detailed explanation of LNG vehicle fuel systems can be found in the subsection titled, **What is LNG?**, which appears earlier in this section. In addition to complex fuel systems, LNG vehicles require engines specifically designed for use with natural gas. As discussed earlier, the selection of natural gas engines is limited, and natural gas engines typically operate on a spark-ignited cycle and do not perform as efficiently as conventional engines for fuel economy. Still, natural gas engine technology has been developing for some time for use with CNG and is more refined than other aspects of LNG vehicle operation. Figures 2-17 and 2-18 show the LNG fuel tanks on a transit bus. Figure 2-19 shows an LNG vehicle tank mounted on a refuse truck.

Figure 2-17. Piping and Control Equipment on a Vehicle LNG Tank

Figure 2-18. LNG Vehicle Tanks Mounted at Rear of Transit Bus Above Engine

Figure 2-19. LNG Vehicle Tank Saddle Mounted on a Refuse Truck

Resources:
Heavy Vehicle and Engine Resource Guide, 2002, U.S. Department of Energy/National Renewable Energy Laboratory, NREL/TP-540-31274.
Natural Gas Vehicle Purchasing Guide, 2002, RP Publishing.

Vehicle maintenance will also be different for LNG vehicles. New skills and equipment will be needed to diagnose and resolve LNG maintenance issues. Maintenance personnel will need to understand the operation of LNG fuel systems, the safety issues of LNG, and the inspection cycles of the LNG vehicles.

Fueling Facilities—LNG fueling facilities have several features that make them unique from other vehicle fueling facilities. LNG is stored in highly insulated storage tanks. LNG tanks are always double-walled, with extremely efficient insulation between the walls. LNG must be maintained cold (at least below -117°F) to remain a liquid, independent of pressure. LNG dispensing requires proper procedures to ensure safe transfer of the cryogenic fuel to the vehicle. However, LNG dispensers are not significantly more complicated than conventional fuel dispensers and can be placed side by side with the diesel or gasoline dispensers in the fueling lane. The complexity and cost of the LNG storage and dispensing system depend on the space available, speed of fueling required, need for defueling capability, and local building code requirements. The LNG fuel station may also require additional maintenance to ensure its proper operation. Further discussion of LNG fueling stations is contained in the earlier subsection **What is LNG?**

Facilities Modifications—Besides the addition of an LNG fueling station, other changes to your fleet's physical facilities may be required. Such facilities as maintenance buildings, fueling structures, parking garages, and other support facilities (including those of contractors who may work on the LNG vehicles) may need modification. All of the facilities where natural gas might be released inadvertently must be given special consideration. Figure 2-20 shows the maintenance facility at Waste Management in Washington, Pennsylvania, which was built new at the beginning of their LNG operation and had combustible gas detection and higher than usual capacity ventilation installed. The best practice is for these facilities to be built or modified based on the designs of a knowledgeable architectural and engineering firm. Proper mitigation strategies for natural gas must be developed in case of an accidental release. In general, the mitigation strategies will include:

- Increased air flow/ventilation
- Combustible gas detectors
- Visual and audible alarms
- Potentially using classified electrical wiring and equipment in certain locations within the facilities.

In general, the older the facility, the higher the cost for upgrades due to more extensive work required to upgrade the ventilation and electrical systems.

Figure 2-20. Maintenance Facility at Waste Management in Washington, Pennsylvania

Implementation Timeline

The implementation of LNG vehicles usually progresses in phases:

- Early planning – collect data, make contacts, and make a plan to move forward.
- Program implementation – complete the purchase process including specifying, ordering, and installing LNG equipment, complete the first round of training activities.
- Start-up – resolve initial problems in the systems, get the vehicles and support equipment up and running on a regular basis, need focus on adequate training and safety procedures.

- Optimization – track and study the vehicle and facility operations, implement changes as appropriate to optimize the operation, resolve problems and issues, integrate training for LNG into standard training activities.

These phases may take two to four years to complete depending on the timing and availability of equipment and support. Running across these time phases are several specific activity categories. Introduction of the new vehicles should be made over time. Furthermore, time must be allowed to troubleshoot, provide training, and educate the staff, management, and local officials. The LNG implementation process is broken down and discussed in this subsection by the following categories. Each category listing includes a summary of some of the activities involved in each category.

- Build the LNG implementation team
  - Build the implementation team (inside & outside the company/at every level of operations)
  - Select personnel who share the commitment
  - Convene a brainstorming session of management & the implementation team
  - Strategize (e.g., timing, needed range, site effects, future expansion)
  - Direct the implementation team to develop a "roadmap" for LNG implementation
  - Assign an individual on the implementation team to oversee each step of the implementation plan (i.e., items listed below)
  - Assign specific responsibilities to implementation team members, and determine deadlines
  - Work with local codes officials (e.g., building and fire code, health & safety officials)
  - Periodically provide updates to senior management

- Start early to collect data and build a network
  - Study the pros & cons of possible alternative fuels
  - Talk to vendors selling new fuels & companies using them
  - Seek the advice of technical experts
  - Gain understanding of the fueling issues (e.g., range, speed, fueling station siting)
  - Meet with your local officials to announce the plan, and seek their input into your site and facility design
  - Continue researching information on fuels & vehicles
  - Send key implementation team members to outside training course(s) (e.g., West Virginia University, National Gas Vehicle Institute, NexGen Fueling)
  - Send implementation team members to conferences and workshops as appropriate to learn more about using AFVs and build your network of knowledgeable individuals

- Build an implementation strategy and plan
  - Weigh all of the factors before deciding on LNG
  - Develop your plan with the help of both the Implementation Team and management
  - Assign a person to lead each facet (e.g., research, review designs, review codes & interact with codes officials, monitor timeline, implement timeline, trouble-shoot, publicize commitment)
  - Plan a strategy for vehicle acquisition, fueling infrastructure, and training
  - Determine what relevant incentives are available
  - Develop a budget
  - Prepare a contingency plan for the event of a shortfall or delay by any of the major participants
  - Prepare a detailed task-by-task integration plan and baseline schedule
  - Revise, update, and proceed with your implementation plan
  - Prepare a "roadmap" to LNG (e.g., design, purchases, implementation, operation)

- Stage the arrival of new vehicles

- Establish corporate commitment for the strategy, as well as provide strong communication and promotion of the LNG program

  - Announce your commitment (as soon as the decision is made to use alternative fuel) to company personnel, stakeholders, and the public
  - Ensure that the people & budget resources will be available
  - Prepare communications materials about the decision to use LNG
  - Prepare an emergency communications plan
  - Distribute the first announcement about your decision to use LNG fuel to company personnel, and stakeholders
  - Use internal staff communications methods to provide regular updates to all personnel
  - Keep staff communications open and active to solicit feedback, as well as identify and resolve issues and problems
  - Consider having an open house or tour of your facilities & vehicles after the work is completed
  - Begin intensive communications with the appropriate key personnel
  - Monitor the staff's reactions and concerns about the new installations and vehicles
  - Hold news conferences for area media
  - Provide regular updates to corporate leadership team, as appropriate, about staff responses & issues
  - Schedule general meeting to provide all staff basic information on safety aspects of LNG & new facilities & vehicles

- The purchasing process

  Vehicles
  - Review the vehicle options and needs (purchase or lease, new or retrofit, make, availability, range, load, performance specifications, cost effectiveness)
  - Prepare request for proposals for the vehicles, fuel, and facility maintenance support
  - Research whether to use tanker trucks or other sources to obtain LNG
  - Oversee the delivery, acceptance, staging & deployment of vehicles

  Facilities
  - Contract with an LNG-experienced A&E firm for a site plan of the LNG fueling facility
  - Consider fueling station options (size, above or below grade, LCNG option, venting, return vented gas back into pipeline, fueling speed, cost implications)
  - Research availability of existing fueling stations (access, proximity, cost tradeoff, use of temporary station)
  - Determine the method for paying for operation & maintenance of the fueling station
  - Determine what upgrades will be needed for maintenance & fuel storage facilities and costs
  - Prepare applications for new permits
  - Supervise construction of fueling station
  - Support discussions with codes officials related to facilities and infrastructure
  - Work with the A&E firm and the construction company on vehicle on-site traffic patterns, storage, staging, fueling & maintenance

- Planning for early operations and problems

  - Continue researching information on facility issues related to LNG installations
  - Optimize equipment, operational processes, and the use of the fueling station
  - Start the operation and troubleshoot any problems
  - Monitor new vehicles & fueling stations to benchmark performance and encourage feedback from personnel

- Training and safety

  Training Strategies
  - Send key mechanics & maintenance personnel to OEM school
  - Develop a training plan for drivers, fuelers, and maintenance personnel
  - Recommend training (who, when, how often, & how to integrate LNG training into existing training process)
  - Conduct mandatory initial training workshops for drivers, fuelers, maintenance personnel, and emergency responders
  - Provide them with handouts describing updated health & safety, emergency response & training information

  Safety Measures
  - Research the risks, health effects, and safety-related characteristics of LNG, the storage facility, and the new vehicles
  - Consult with local, state health departments about fuel effects, related accidents, and hazards
  - Revise the company health & safety, emergency response, & training plans
  - Prepare information sheets, data-specific materials, & posters explaining potential risks related to LNG
  - Monitor accidents as well as concerns & issues from personnel related to LNG fuel, vehicle performance, and the storage facility
  - Plan mandatory, periodic safety updates & retraining sessions

Build the LNG Implementation Team

This LNG implementation team will be the group that leads every phase and aspect for the LNG implementation. This team will work through the purchasing process and prepare for early operations and problems. As the vehicles and infrastructure come online, this team will evolve from implementation to optimization of the operation of the vehicles and infrastructure, and work to resolve ongoing issues. Once the LNG equipment is up and running, some of the problems may be complex and require study and data collection in order to address each problem properly. This team will lead these troubleshooting activities.

Depending on the size of the transportation organization and the phase of implementation, the LNG implementation team may include one or two or maybe 15 or more people. The team must include all aspects of the transportation organization to make sure that the implications of the introduction of LNG can be discovered, discussed, and a strategy can be built. The members of the team should include operations and facilities personnel, mechanics, drivers, engineers, management of each major department, training, and others as appropriate. This team may go beyond the transportation company and include trusted vendors and consultants as needed.

Someone will need to be designated as the leader of this team (probably assigned by management). This leader must be willing to become a champion of LNG and learn everything that they can about the fuel, implementation, and safety. Management must be willing to provide this leader with the resources to properly plan for the LNG operation and work through the eventual problems that will come up.

The reasons for creating this LNG implementation team are simple – in order to be successful, the entire organization needs to buy-in to the new technology and the process, and commitment is required to successfully plan, implement, start-up, and optimize new technology introduction. As an example, standard operations such as fueling, which are taken for granted on conventional vehicles, may involve additional thought, consideration, and preparation when performed on LNG vehicles.

This need for extra effort will extend to nearly every aspect of vehicle operation, especially during the start-up phase. Before deciding to implement LNG vehicles at your site, you should be aware of the additional effort that will be needed at all levels of your organization and be willing to commit to the successful operation of LNG vehicles. This extra effort will include educating all personnel as well as training those working directly with the new fuel, vehicles, fueling station, or other new equipment. This need for additional labor should decrease over time, as the technology is better understood, but the use of LNG will most likely continue to require some extra effort, compared to the conventional fuels.

New technologies like LNG are not only new to you; they are often new to the vehicle manufacturers and other organizations that you may typically rely on for support. In order to successfully implement LNG vehicles, it is best to develop your own experts who will be able to address complex technical challenges when they present themselves. Fleet managers and maintenance personnel should not expect that vehicle manufacturers and other support organizations will be immediately responsive or familiar with the types of problems that will be encountered or with the appropriate solutions. Only by completely understanding the vehicles that you operate and the support infrastructure will you be able to help yourself in the type of time frame that you are accustomed to. You will still want the vendors to support their equipment, but you will want to be proactive and take a scientific approach to troubleshooting.

This implementation team should meet often to work through the planning and implementation process. Also, this group needs to have an open mind and be motivated and creative in addressing problems. The team may need to add members for specific tasks and issues as well as include the vendors as part of the team. This team must also make themselves available to other staff to share information whether it is a question from staff or information that the team can share.

Start Early to Collect Data and Build a Network

Everything about LNG may be new to you at the beginning. It is important to start early in the process of considering the implementation of LNG vehicles by collecting data, building a network of experts, vendors, and other fleets, and building the implementation strategy (or roadmap). The hardest parts of implementing LNG vehicles are getting started, finding resources (funding, reports, and web sites for information and background), and finding experts and vendors to begin the process of developing your own LNG vehicle operation experts. At the beginning, what you lack most is experience on which to base decisions.

Before deciding whether or not to implement LNG, you should learn as much as you can about the specific changes that you would need to execute and consider the effects that these changes would have on your fleet. In order to do this, you will need to collect all the information necessary to understand the LNG fuel, LNG technologies, and the best strategies for implementing LNG within your particular fleet. Here are some suggested sources:

- Access all the relevant web sites for background information needed to make good decisions (note: many references to government, commercial, and trade association web sites are included throughout this *Resource Guide*). Tables 2-4 and 2-5 provide a must-have list of reports and web sites that should be considered a starting point.
- Analyze your service routes to determine the number of vehicles needed for your service area and a technical description of your service duty cycle from the vehicle operation perspective.
- Examine your budget and determine what can be allocated for the new LNG vehicles.
- Attend LNG, natural gas, and other AFV conferences and meetings where you can learn more as well as develop contacts and identify support groups; it is especially important to talk with OEM representatives, fuel providers, and LNG users at conferences and exhibits; actively look for funding sources and work to understand available credits. Table 2-6 provides a list of some conference sponsors that should be considered.
- Review environmental and building regulations prior to site planning to accommodate the new fueling infrastructure.
- Contact your local building codes officials and the fire marshal in your area; make sure these officials are included in planning for facility modifications and additions in preparation for LNG.
- Study your facility's site drawings to anticipate modifications and additions.
- Consult with an experienced Architectural & Engineering (A&E) firm with relevant experience specifically in LNG to provide options and accurate cost estimates.
- Obtain descriptions of site modifications, needed infrastructure, and safety equipment needed for your site(s).
- Take tours of similar facilities where LNG facilities have been installed.
- Purchase or gain access to alternative fuels technical manuals for vehicles and infrastructure.
- Attend training courses on LNG vehicles and infrastructure.

In order to focus your data collection efforts and create your implementation strategy, you will need to research the topics listed below as well as other topics as they come up during the planning and implementation process. These topics are some of the basic issues that should be investigated in detail before beginning to implement LNG within your fleet. Many of these issues are discussed in other subsections of this resource guide, in which case the associated subsection is shown in parentheses.

1. Fuel characteristics, fuel energy content, vehicle fuel system, and the LNG saturation curve (**What is LNG?**).
2. How to calculate energy content and energy equivalent gallons.
3. Fuel purchasing and delivery strategies.
4. Managing heat input and venting of LNG.
5. The size of the on-board fuel storage, and its influence on duty-cycles and range.
6. Available engine technologies (e.g., restricted types, horsepower and torque options) and an engine specification table for available technologies.
7. Selecting dual-fuel or single fuel vehicles.
8. Understanding how the on-board fuel system works, especially the effects of different sizes of on-board tanks (**What is LNG?**).

Table 2-4. The Must-Have List of Reports for LNG

Topic/Report	Report Number	Where to Order
General Information		
Liquefied Natural Gas: Alternative Fuel of Choice	CD-ROM	www.nexgenfueling.com
NGV Resource Guide		www.ngvc.org
The Clean Fuels and Electric Vehicles Report		www.energy-futures.com
Funding/Getting Started		
Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations	TCRP Report 38	www.trb.org
Liquefied Natural Gas for Heavy-Duty Transportation		www.gastechnology.org
Natural Gas Buses: Separating Myth from Fact	NREL/FS-540-28377	www.afdc.doe.gov
Natural Gas Vehicle Purchasing Guide		www.afdc.doe.gov
Fleet Start-Up Experiences at the AFDC	Several	www.afdc.doe.gov/pdfs
Vehicles		
Reference Guide for Integration of Natural Gas Vehicle Fuel Systems	GRI-02/0013	www.gastechnology.org
Heavy Vehicle and Engine Resource Guide	NREL/TP-540-31274	www.afdc.doe.gov
Recommended Practices for LNG Powered Heavy-Duty Trucks	J2343	www.sae.org
Vehicle Maintenance and Operating Manuals		From OEMs
Fueling Station and Facilities		
Risk Management Plan Guideline for LNG Vehicle Fueling Stations	GRI-98/0245	www.gastechnology.org
Qualitative Risk Assessment for an LNG Refueling Station and Review of Relevant Safety Issues	INEEL/EXT-97-00827 rev 2	www.inel.gov
Clean Air Program: Design Guidelines for Bus Transit Systems Using Liquefied Natural Gas (LNG) as an Alternative Fuel	DOT-FTA-MA-26-7021-97	www.ntis.gov
Operating Manuals for Safety Equipment including servicing procedures for combustible gas detectors		From OEMs
Safety and Training		
Introduction to LNG Safety		www.ch-iv.com
Clean Air Program: Liquefied Natural Gas Safety in Transit Operations	DOT-FTA-MA-90-7007-95-3	www.ntis.gov
Introduction to LNG for Personnel Safety	X08614	www.aga.org
Introduction to LNG Vehicle Safety	GRI-92/0645	www.gastechnology.org
Clean Air Program: Summary of Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuel	DOT-FTA-MA-90-7007-95-1	www.ntis.gov
Standard for Liquefied Natural Gas (LNG) Vehicular Fuel Systems	NFPA 57	www.nfpa.org
Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG)	NFPA 59A	www.nfpa.org
Proceedings of Liquefied Natural Gas Vehicle Systems: Training School		www.nexgenfueling.com

9. New infrastructure for fueling, changes to existing facilities, and other modifications that might be needed (**What is LNG?; What Are the Safety Considerations for LNG Vehicle Operations?**).
10. Procurement of new safety equipment, how it works, manufacturers, sensors and warning systems, as well as above or below grade issues (**What Are the Safety Considerations for LNG Vehicle Operations?**).
11. Increases in personnel and technical resources required for operating consistently.
12. Understanding incentives and sources of grants and tax credits (**Why Alternative Fuels?**).

Table 2-5. The Must Have List of Web Site Resources

Web Site	Source Web Site
Alternative Fuel Data Center	www.afdc.doe.gov
Clean Cities	www.ccities.doe.gov
Natural Gas Vehicle Coalition	www.ngvc.org
EPA Office of Technology and Air Quality	www.epa.gov/otaq
Gas Technology Institute	www.gastechnology.org
Alternative Fuel Vehicle Fleet Buyer's Guide	www.fleets.doe.gov
CARB Moyer Program	arbis.arb.ca.gov/msprog/moyer/moyer.htm
Society of Automotive Engineers	www.sae.org
Natural Gas Vehicle Institute	www.ngvi.org
Alternative Fuels Training Consortium	naftp.nrcce.wvu.edu

Table 2-6. Sponsors of Conferences and Meetings that Regularly Include LNG Vehicles

Meetings/Sponsors	Web Site
Natural Gas Vehicle Coalition	www.ngvc.org
Clean Cities, national and local	www.ccities.doe.gov
Society of Automotive Engineers	www.sae.org
American Public Transportation Association	www.apta.com

Build An Implementation Strategy and Plan (The Roadmap)

The development of the implementation and strategy plan is critical especially in the early stages of planning for LNG. This plan should describe all of the activities and timing, the business plan for the LNG program (how much money is needed and where is the money going to come from), and an overview of responsibilities of staff for each aspect of the program. This plan needs to be flexible and will need to be modified many times before the LNG operation becomes routine. One of the most important parts of this plan will be the definition of success of the LNG implementation and operation. The plan will need to describe what the goals of the program are and what success is, so that you will know when you have it.

Another key aspect of this plan is how you phase-in the LNG operation. Having vehicles without fuel or fuel station is not useful. In general, you want facility modifications and installation of the fuel station before anything else. You will want to make sure fuel will be available before or about the time that the LNG vehicles arrive. Training is extremely important and should start well before any of the equipment arrives on-site. You may want to have only a few vehicles arrive at the beginning so that the fueling, facility, and vehicle LNG systems can be checked out and changes made as needed.

Table 2-7 provides a general outline of the implementation strategy and plan (The Roadmap). This document is intended to evolve over time. In the beginning, the document can be used to define the work to be completed. As progress is made, this document can be used to track progress and define new tasks as the need arises. This plan should be defined to best suit your needs. Also, this plan should be updated on a regular basis as the implementation team meets over time.

Table 2-7. General Outline of the Implementation Strategy and Plan (The Roadmap)

Introduction/Background – describe the general factors pushing the use of LNG
Objectives of the LNG Program – success will be based on this
The Implementation Team – describe the staff needed to be involved and responsibilities
Business Plan – estimated costs of the program and where the money is going to come from
Operations – describe the expected use of the LNG vehicles
Vehicles – describe the potential options of technology to choose from
Fuel Purchase – describe the fuel requirements including how much, source, and cost
Support Infrastructure – on-site fueling, facility modifications
Safety – risk management and procedures
Training, Training, Training – every impact of LNG operation must be incorporated into training programs
Phase-In Strategy and Timeline – description of overall timing strategy and progress to date
Action Items – track action items defined and progress towards completion

Corporate Commitment, Communication, and Promotion

Corporate commitment is critical to the success of the LNG implementation. This commitment sets the tone for the organization. Commitment means using funds, personnel, and work time, as well as patience and persistence to absorb this new technology into day-to-day operation. Once the Implementation Strategy and Plan has been completed, this plan needs to be made available to the senior corporate members of the company as well as managers and staff for review, comment, and buy-in. Everyone in the organization needs to eventually buy-in to the LNG implementation if it is to be successful. This will also mean that ongoing and complete communications are necessary for the implementation team, senior management, and the staff.

Strong communication and promotion within the team, with corporate managers, and with the public can help ensure good coordination and quick response to issues that arise. This coordination and quick response will help preserve budgets and maintain schedules. Make sure that you take advantage of intangible benefits from public relations opportunities such as grand openings for fuel stations and facilities; good will from regulators; coordinate with the fire marshal and building codes officials as early as possible; educate the public and local officials; and create a cooperative environment inside and outside the company.

While using LNG may complicate your fleet operations, and cause increased expenses, there are many benefits that can arise out of using LNG, though most of them are hard to quantify. Your organization can take pride in the fact that they are helping to develop new technologies that will improve both the environment and our nation's fuel security. With the proper publicity, an LNG program can help to improve your organization's image. This will allow your customers and your surrounding community to take satisfaction in the technological progress made through your organization. These benefits can have a significant effect on the public perception of your organization in the long run, and can also help motivate your employees.

Some of the potential communications and promotions available are as follows:

- Promote your commitment to reducing emissions to the public.
- Take advantage of the opportunity of the enhanced company image and "green" marketing opportunities.
- Communicate your commitment, including a description of the new fuel technologies involved, to all personnel, company directors, stockholders, and stakeholders (i.e., local and state officials, clients, plant neighbors, and city and county permit agencies).
- Hold regular follow-up meetings or send company-wide e-mails/newsletters to all personnel, beginning when you start the analysis of whether to use an alternative fuel and continuing after the vehicles are on the road.

The Purchasing Process

The purchasing of LNG equipment (or any new technology equipment) requires several steps in chronological order as follows:

- Homework – investigate the options and available products as well as exactly what is needed including funding.
- Specification – determine the appropriate specifications for the equipment needed.
- Order – send out requests for proposal and award a contract for the equipment desired.
- Installation – have the equipment delivered, installed, and tested/verified that it is working properly.

As with any purchase, homework is required to learn about the product options for what you wish to purchase and to match those options to what will best fit your operation. You will also need to study your own operation and fully characterize the requirements for the equipment purchases. This can be done internally or by hiring a consultant experienced in preparing and choosing equipment for LNG operations; however, the transportation company should remain in the lead and control of the implementation. The ultimate goal in this process is for the fleet to operate LNG vehicles in a cost-effective manner as soon as possible, this requires that the fleet become their own expert in LNG vehicle and infrastructure as soon as possible. As part of homework, the search for funding internally and from federal, state, and local sources should be investigated, see **Why Alternative Fuels?** for more information on incentives.

This homework should be considered a part of the data collection and network-building activities described above and may include collecting data on the Internet, talking with other fleets that operate LNG vehicles, vendors, and other documentation. Specific topics for this homework may include characterizing average vehicle duty cycle in your operation, number of LNG vehicles desired, amount of LNG required to be stored/available on-site every night for fueling, vehicle storage, vehicle maintenance requirements, current training practices, and others.
As mentioned earlier, the products to be purchased may include some or all of the following:

1. Fuel
2. Vehicles
3. Architect & Engineering (A&E) work to plan and execute facility installation and modification
4. Fueling infrastructure
5. Facility modifications

Fuel – the LNG fuel purchase options can be complicated depending on the source of the fuel and how much is required. Several questions need to be investigated and clearly answered:

1. How close are you to an LNG production facility?
2. Should you consider small-scale liquefaction on-site or close-by?
3. Is using landfill gas converted to LNG available or an option close-by?
4. Do you wish to own or lease your LNG fueling facility or is there a dispensing facility close-by that would be acceptable?
5. Should you purchase LNG on a long-term contract or on the spot market?
6. Who are the vendors for the fuel?
7. How often would you need fuel?

<u>Calculating energy content and energy equivalent gallons</u> – This is probably the most confusing part of using LNG. First, we need to define a "standard" gallon of LNG, which would be a gallon of LNG at atmospheric pressure. This standard LNG gallon has a general or average energy content of 73,500 BTU/gallon assuming that the LNG has high methane content (99%) as discussed earlier (**Fuel Differences** above). Many people feel that the best way to make sense out of LNG volumes is to use mass measurements instead, and in general, all true measurements of LNG are based on mass and then converted to the volume measurement desired.

The confusion here begins when you look at an LNG dispenser display that reads out in gallons of LNG dispensed. These "volumetric" gallons of LNG are <u>not</u> standard LNG gallons because the fuel is dispensed under pressure. The density and energy content of a gallon of LNG decrease as the pressure increases (see **LNG Saturation** in **What is LNG?**). The volumetric

LNG gallons dispensed at the fueling site are important for knowing how many gallons were placed on-board the vehicle and determining if the on-board fuel tanks are full. However, the number of standard gallons of LNG are a lower number than the dispensed (or volumetric) gallons of LNG based on the density measurement (mass per volume) at the dispenser. Assuming that the LNG is dispensed at saturation, the pressure of the dispensed gallon indicates the density of the fuel and can be easily converted to standard gallons. The fuel station dispenser vendor should provide this conversion factor.

The LNG dispenser at the fueling station and the measurement of LNG delivered by a tanker truck are always (or should always be) originally measured in a mass measurement and then converted to a gallon measurement. For the LNG dispenser, the fuel mass measurement is converted into volumetric gallons on the display by measuring the density or mass per volume. For the LNG tanker truck, the mass measurement of the LNG delivered to the LNG fueling station is converted into standard LNG gallons for billing purposes by using a density measurement supplied by the plant at which the LNG was produced, usually around 3.53 lbs/gal for high methane content fuel.

This understanding of energy content and standard LNG gallons is important for properly measuring the fuel economy of an LNG vehicle (based on energy content) and for balancing the number of gallons of LNG placed into your fueling station and the number of gallons of LNG dispensed from your LNG station. For the fueling station, if you do not properly compensate from dispensed volumetric gallons to standard gallons of LNG, it will appear that your fueling station has magically been producing LNG well beyond the amount that had been delivered.

<u>Selecting LNG storage volume required for vehicles and on-site fueling station</u> – The volume of LNG required for on-board the vehicles is based on several factors:

- The range and duty cycle that a typical vehicle operates at the site
- The expected fuel economy of the vehicle's engine on that duty cycle
- A little more LNG on-board storage for a cushion or margin of error in the first two factors
- Number of vehicles purchased now, and possibly in the future

As shown in the previous discussion, make sure that this calculation of on-board LNG fuel storage is completely understood including pressure compensation of the LNG on-board the vehicle, and that a clear and complete description of duty cycle and range of the vehicle have been made. Idle time for the vehicle is a critical item to be understood for the duty cycle, because the spark-ignited natural gas engine consumes more energy at idle than the standard diesel compression ignition engine.

The volume of LNG required for storage on-site at the fueling station is based on the amount of fuel consumed each day by each vehicle, and the number of vehicles planned for operation now and potential additional vehicles in the future. The method and ability of the fuel supplier to provide LNG on a timely basis must also be considered here. The user must have a contingency plan for possible interruptions of fuel supply as well.

There is more information available in a later subsection, **Is LNG Readily Available?**

Vehicles – One of the most important issues is to make sure that the vehicles and fueling station are designed to operate sufficiently within the expected duty cycle. An LNG vehicle fuel system is more sophisticated and significantly different from the conventional fuel system, because it stores and delivers cryogenic liquid under pressure. The engine operation may also be less efficient than diesel operation, which can inhibit vehicle range if not properly accounted for in the vehicle design. The vehicle and fueling station should be designed to fuel the vehicles at a speed that will not disrupt normal vehicle operation. Furthermore, the on-board fuel storage system should be designed to hold as much fuel as is required to achieve the desired range. In addition, the fuel system should be designed with the ability to defuel the vehicle fuel tanks in order to perform maintenance. If fleet mangers are aware of the range requirements and duty-cycle that will be needed to smoothly incorporate the LNG vehicles into their fleet, they should be able to obtain vehicles that will perform to these specifications. Clearly stating these needs up front will minimize the operational changes that will need to be incorporated upon implementation of the new vehicles. Figure 2-21 is an LNG shuttle bus in Austin, Texas and Figure 2-22 is an LNG refuse truck in Washington, Pennsylvania.

Figure 2-21. LNG Shuttle Bus in Austin, Texas

Figure 2-22. LNG Refuse Truck

Available funding and emissions certification levels for engines and vehicles need to be considered when choosing natural gas vehicles. Many funding programs from the federal and state programs require a calculation of air quality savings based on using the alternative fuel vehicles. These savings would be based on the engine certification emissions levels from the EPA (www.epa.gov/otaq/certdata.htm) or California Air Resources Board (CARB) compared to the emissions levels provided in Table 2-1. These emissions savings calculations are described on the Moyer program web site at CARB – arbis.arb.ca.gov/msprog/moyer/moyer.htm.

Available engine technologies – In general, there are two types of natural gas engine technologies. The first is the single-fuel natural gas engine, which operates on a spark-ignition cycle similar to a gasoline engine. The second type is a dual (or two) fuel natural gas engine, which uses natural gas for the majority of the fuel and some diesel fuel to enable the combustion process in a standard compression ignition diesel engine cycle. The diesel fuel acts as a chemical spark plug. The advantage of the dual-fuel natural gas engine is that the emissions can be reduced from standard diesel and the loss of fuel economy in most applications is minimal (less than 5%). The single-fuel natural gas engine for a heavy-duty application can have a fuel economy penalty of 15% up to 30% compared to a standard diesel engine. However, the single-fuel natural gas engine is capable of achieving much lower emissions than the current dual-fuel natural gas technology.

Another issue is purchasing a retrofit for an existing or newly purchased vehicle or purchasing a new original equipment manufacturer (OEM) natural gas engine and fuel system integrated into a new vehicle. In general, the OEM natural gas engine and fuel system integrated into a new vehicle is the best solution from an emissions and cost of maintenance position. However, there are times when it would be more convenient to start with converting existing vehicles rather than purchasing all new vehicles. One such case would be when only a few new vehicles are purchased each year and the LNG fueling station that is being installed can accommodate many more vehicles than just the new ones. This can be a compelling situation when the fueling station is being supplied by landfill gas being converted to LNG on-site.

The vehicle natural gas fuel system and added safety features are covered further in two subsections in this report – **What is LNG?** and **What are the Safety Considerations for LNG Vehicle Operations?**

Resources:

Heavy Vehicle and Engine Resource Guide, 2002, U.S. Department of Energy/National Renewable Energy Laboratory, NREL/TP-540-31274.
Natural Gas Vehicle Purchasing Guide, 2002, RP Publishing.

Facilities (Fueling, Maintenance, and Vehicle Storage)

Early in the process of implementing LNG, you should hire an architect & engineering (A&E) firm that is experienced in converting facilities to operate with natural gas vehicles and specifically LNG. This firm should be hired to review the existing facilities and create options for you to review and consider for conversion to operating natural gas vehicles. This firm should review all of the buildings and consider whether or not the LNG vehicles might ever be inside and what the mitigation process for accidental release of natural gas might be. The facilities of most concern are the vehicle maintenance and storage buildings as well as the fueling lanes and any structures associated. The next issue is the location to install and size of an on-site fueling station (if determined to be necessary and desired). The options should have cost estimates provided so that realistic choices can be made. Also, the local building codes officials should be included in the process as soon as possible for their input and buy-in.

As mentioned earlier, the general mitigation strategies for accidental release of natural gas within structures will include:

- Increased air flow/ventilation
- Combustible gas detectors
- Visual and audible alarms
- Potentially using classified electrical wiring and equipment in certain locations within the facilities.

These safety systems are discussed in more detail in the following subsection, **What Are the Safety Considerations for LNG Vehicle Operations?**

The fueling station installation and the facility modifications have several aspects that will need your attention and study. For the installation of the fueling facility, the following issues need to be addressed:

- Spend the time and resources necessary to understand fueling needs, duty cycles, range, speed, grades along routes, idle time, siting issues for installing fueling infrastructure, personnel training, and methods to ensure timely fuel deliveries.
- Be sure expandability has been taken into account.
- Determine if liquefied to compressed natural gas (LCNG) is desired.
- Ensure access to dependable experts for troubleshooting and optimizing the fueling station.
- Understand the siting regulations and codes and include local codes officials as soon as possible.
- Time the arrival of the new vehicles to the availability of the fuel.
- Ensure that resources are available for operating and maintaining the fueling station (if on-site fueling).
- Study the safety equipment required for the fueling station and options for natural gas leak detection, fire detection and suppression, and monitoring.
- Determine that reliable and cost effective fuel is available.

There are natural gas fuel suppliers that are willing to install and own the fueling equipment, provide fuel, and maintain the fueling facility for a cost that would be loaded into the cost of fuel and usually presumes a guaranteed amount of fuel consumption and sales. This can be a cost-effective solution.

Another issue is the need to maintain the equipment. There are companies that can be hired to service this equipment. There is also training available so that your own staff can learn to take care of these safety systems and equipment. However, the cost of supporting the fueling station and supporting the safety systems in the facilities is not a minor activity and can be quite costly.

<u>Heat management and venting for LNG storage systems</u> – all LNG fuel storage systems whether for the vehicle or for the fueling station are designed to minimize heat input into the system. The storage containers and piping are usually well insulated to reduce heat entering. However, the LNG will eventually heat up and need to vent. The goal in designing any LNG system is to use the stored fuel and replace it with colder and newer LNG. Even with all of this engineering, the LNG will heat up over time and the pressure in the storage container will begin to rise if the fuel is not used. The pressure in these LNG systems will eventually cause pressure relief devices to allow some of the fuel and pressure to be released. On the vehicle, this release of natural gas will be to the atmosphere or possibly inside a service building. For the fueling station, this release may be to the atmosphere as well. Some stations are set up to collect that natural gas and use it for other things such as heating or in conjunction with an LCNG operation at the station. As mentioned earlier, methane (or natural gas) is a greenhouse gas and therefore the release is not a desired event. Also, LNG is a premium fuel and the release of it into the atmosphere is a loss of product and money.

Another issue with venting is "weathering" of the LNG. As discussed earlier (**What is LNG?, Weathering of LNG Fuel**), LNG is composed of primarily methane but has other heavier hydrocarbons and gases. If the LNG in a vehicle tank or in the bulk storage tank is not used, over time, the methane will boil off first and be vented from the LNG system. This venting will cause the amount of other hydrocarbons and other gases to increase in concentration in the LNG liquid in the tank. As long as the fuel in the tank is used and new (cold) LNG is added on a regular basis, this weathering should not be an issue for your operation.

Planning for Early Operations and Problems

As the start-up of LNG vehicle operation comes closer, plans are needed for resolving problems. Assurances of support from the vehicle and fueling vendors will be needed. These assurances should come in the form of having technical staff available to be on-site or be able to provide quick on-site support for problems that arise. The testing of infrastructure equipment and vehicle equipment should be done with only a few vehicles first to work all the final issues out. During all of these activities, the user should have personnel watching and learning about the problems and how to troubleshoot those problems in the future. These activities will be an extra expense, but will be required to optimize the operation in the future. Some sites have had significant issues during start-up that have required days, weeks, even months to resolve.

LNG Start-Up Experiences:
Raley's LNG Truck Fleet Start-Up Experience www.afdc.doe.gov/pdfs/raley-lng.pdf
Waste Management's LNG Truck Fleet Start-Up Experience www.nrel.gov/docs/fy99osti/26617.pdf
DART's LNG Bus Fleet Start-Up Experience www.nrel.gov/docs/fy00osti/28124.pdf

Other Alternative Fuel Vehicle Start-Up Experiences:
UPS CNG Truck Fleet Start-Up Experience www.afdc.doe.gov/pdfs/ups_cng.pdf
Dual-Fuel Truck Fleet Start-Up Experience www.afdc.doe.gov/pdfs/pimagro.pdf
Ralphs Grocery EC-Diesel™ Truck Fleet Start-Up Experience www.afdc.doe.gov/pdfs/Ralphs_ECD.pdf
Denver SuperShuttle CNG Fleet Evaluation www.ott.doe.gov/pdfs/supershuttle.pdf
Class 8 Trucks Operating on Ultra-low Sulfur Diesel with Particulate Filter Systems: A Fleet Start-up Experience SAE paper #2000-01-2821, October 2000 [Available for purchase at www.sae.org/]

Training and Safety

The training aspect of LNG operations is also extremely important. All personnel should be aware of the considerations associated with the fact that LNG is a cryogenic liquid as well as a fuel. Personnel who work around or handle LNG should be required to be trained in the proper handling, what to expect, and how to react in case of an accidental spill or vapor release. When using a new fuel and with new equipment on-site, it is important that all personnel are provided with complete and accurate descriptions of the new facilities and receive proper training and information. Further information on training can be found throughout this *Resource Guide*, and particularly in the subsection, **What Are the Safety Considerations for LNG Vehicle Operations?**

Some of the general aspects of safety and training for LNG are as follows:

- Ensure there are resources for adequate training and education for personnel about the new technology, infrastructure, fueling, and operational procedures.
- Provide training to all personnel including management; integrate training related to the new technologies into your routine training programs (details are provided in the subsection titled **What are the Safety Considerations for LNG Vehicle Operations?**).
- Fully integrate new procedures and information into existing training manuals and sessions.
- Increase safety awareness.

How Do We Resolve LNG Problems?

Over the course of any new system implementation, problems will occur. LNG is no exception to this rule. As most fleet mangers have probably experienced, any change to the daily fleet operations, even a change as small as implementing a new scheduling or route assignment process, can cause difficulties. These difficulties are magnified when they can have safety ramifications in addition to performance ramifications. The key to addressing these problems when they occur is to anticipate them before they occur. By considering how you would address the many types of problems that can occur with an LNG vehicle operation, you will be better prepared to answer the question: What do I do when my LNG systems don't work?

Make Sure Adequate Information is Available

When a problem occurs, the first objective will be to determine what the problem is. In order to do this, you must have knowledgeable personnel available to analyze the problem. Training is emphasized throughout this resource guide, but its payoff is greatest when problems occur. Developing as many on-site experts as possible will allow your fleet to address issues quickly and effectively to minimize vehicle downtime, and enhance performance. It is also important to make sure that training is kept up-to-date and personnel are familiar with the basic concepts of LNG vehicle operation and what to do if there is a problem.

It is important to know many aspects of the specific equipment installed at your site. For each piece of equipment, it is important to know at least the following information:

- Its function or purpose
- How it works
- How it is expected to perform under normal conditions (standard temperatures, pressures, flow rates, etc.)
- What regular maintenance it needs
- What maintenance has been performed on it (maintenance records)
- How it may fail
- How to repair it
- When and how to replace it

- When to seek the help of outside sources
- How to disable it in an emergency

Personnel should be trained to know much of this information, but it is also important to have the resources on hand that explain all of these things. Maintenance manuals and other information resources should be available on-site in convenient locations. Written materials, in addition to well-trained personnel, are a crucial aspect of resolving LNG problems.

You may also want to consider that equipment breakdowns of facilities, fueling stations, and vehicles can occur at any time of the day, especially if normal operations continue through the night. Placing knowledgeable personnel on-call can help your fleet to address breakdowns quickly so that equipment can return to service.

Beyond keeping information available within your organization, developing relationships with the vehicle manufacturer, tank manufacturer, fueling station designer, and other entities that have provided you with new equipment will be important when problems develop. It is important to know whom to contact for information and assistance regarding all of your LNG equipment. Other fleets with LNG experiences can also be an effective source of information when dealing with LNG problems. Some problems may be non-technical and simply relate to logistics and optimization, such as timing fuel deliveries, and scheduling regular maintenance. When considering these types of problems, it is especially helpful to use the experience of others who have been through this before. Networking with sources outside of your organization can provide you with information that will help you know how to approach difficulties when they occur.

Implement Practices to Prevent Problems

Besides knowing what to do and where to get information in the event of an LNG problem, there are several practices and strategies that you can implement to reduce the frequency of incidents, and resolve LNG problems.

Implementing an inspection strategy will help to identify many problems before they impact vehicle and facility safety and performance or cause breakdowns. The degree of inspection required may vary for different fleets and different applications. When developing an inspection strategy you should consider the following:

- Inspection costs in view of the costs of potential failures, including lost productivity, and repair costs.
- The vehicle and fueling station operation cycle involved.
- The potential duration damage may exist undetected before causing failures.
- Existing inspection schedules for other systems.
- Equipment availability.
- Inspections required by regulations.

Strict and detailed record keeping is essential during inspections and all maintenance. This will aid in adherence to maintenance schedules, ensuring required maintenance is performed before equipment is returned to service, and analyzing the success of existing inspection schedules. Documented maintenance records will also be helpful in the event of a problem or breakdown to identify the past performance of the failing equipment, and the previous countermeasures.

A key aspect of preventing LNG problems is to control access to the LNG systems and equipment. It may be obvious that only qualified personnel should be given responsibility to inspect or repair LNG equipment. However, control issues can enter into nearly every aspect of vehicle operation. Only drivers familiar with LNG vehicles should be assigned to operate them. Only staff members that are familiar with LNG fueling techniques should perform fueling. Washing of vehicles needs to be performed with care to ensure moisture does not damage vent piping or other fuel system components. Painting, tire changing, and other seemingly routine tasks may involve special considerations when performed on LNG vehicles as opposed to diesel or gasoline vehicles. Special considerations may be needed for routine or other maintenance performed off-site by inexperienced personnel. Fueling stations and other facilities that are specially designed for LNG use are also vulnerable to misuse by unqualified personnel. Fleet managers need to control assignments for performing specialized tasks and using specialized equipment in order to ensure that they understand the proper considerations involved.

Keeping a supply of spare parts on hand for both the vehicles and the fueling station will also help speed repairs when they are necessary. Redundancy can also be designed into a fueling station for the same reason. Whatever precautions are necessary must be taken to ensure that a minor failure cannot cause major vehicle downtime, or in the case of a fueling station breakdown, hold up the entire fleet.

Prepare for Possible Problems

The best way to prepare for all of the possible problems that may arise concerning LNG vehicle operation is to consider the types of problems that may occur and develop strategies for approaching each problem. Make sure that you discuss problems that other fleets have encountered, and stay up-to-date on their progress in resolving those problems. The following lists outline some possible problems that can occur concerning the vehicles, fueling station, and other facilities.

Vehicles

- Mid-route breakdowns requiring road calls
- Fuel system leakage
- Fuel system component failures
- Loss of fuel tank vacuum
- Engine/drive-train problems
- Combustible gas detector activation while in service
- Collisions/Accidents

Fueling Stations

- Failures of pumps, heat exchangers, fuel dispensers, and other equipment
- Fuel spills
- Fires or other emergency situations
- False activation of gas and fire detection equipment

Other Facilities

- False activation of gas and fire detection equipment
- Ventilation system failure
- Fires or other emergency situations

An emergency plan, which is discussed further in **What Are the Safety Considerations for LNG Vehicle Operations?**, will address many of these issues. Most of the other issues concern the functionality of vehicles and equipment. Solving these problems will require accessing the proper information, personnel, and equipment. There may also be short-term solutions, which will keep up productivity, such as using spare vehicles or alternate fueling sites. It should be noted that LNG vehicles will vent fuel if not used regularly.

Optimization

The important thing to remember when implementing LNG vehicle operations is that this new technology is still in development. The responsibility will often fall on the fleet to solve their own problems and analyze their own systems. It is very important for the fleets to embrace the new technology, not only learning as much as they can about LNG vehicles in general, but also studying the patterns and behaviors of their particular systems and operations to improve overall performance.

What Are the Safety Considerations for LNG Vehicle Operations?

Like any fuel, safe handling procedures, and proper safety precautions must be followed when working with LNG. Many years of experience using NGVs have proven that natural gas can be used safely as a fuel for vehicles. However, using LNG, or any alternative fuel, involves different safety issues than most fleet personnel are accustomed to. The key to safely operating LNG vehicles is considering the procedures, equipment, and training that must be implemented within an LNG vehicle operation. Safety and training could be enhanced by using an architect and engineering firm experienced in LNG for site planning, facility modifications, installations of equipment, and emergency procedures. Training should be enhanced with expert training from third parties and vendors. The local codes officials and fire safety personnel should be included in planning, training, and emergency preparedness exercises.

The information provided here on safety and training is intended to be a general summary and is not intended to be complete. Each fleet operator needs to spend the time to be their own expert on safety and training issues for their site. This will require training the trainers by sending them to school on LNG operations and safety. This may also include hiring an expert consultant for various parts of the safety and training aspects of LNG.

There are several topics covered in this subsection as follows:

- Effects of LNG characteristics on safety
- LNG codes and standards
- Potential hazards associated with LNG
- Vehicle specifications
- Vehicle operations and maintenance
- Fueling facilities
- Maintenance and parking facilities
- Transporting LNG
- Personal protective equipment
- Emergency response
- Safety and training

Effects of LNG Characteristics on Safety

Before discussing the specific safety considerations for LNG vehicle operation, it will be helpful to reexamine the characteristics of LNG and how they affect safety considerations. A more detailed discussion of LNG characteristics can be found in the earlier subsection **What is LNG?** Derived from natural gas, LNG is a clear and odorless liquid that, like other forms of natural gas, is not toxic, corrosive, carcinogenic, or a threat to soil, surface water, or ground water. If LNG fuel is spilled, it will dissipate rapidly into the atmosphere, causing no lasting problems for the soil.

LNG is a compact form of natural gas. One cubic foot of LNG will vaporize into 618 cubic feet of natural gas at atmospheric pressure (618:1). When LNG is saturated, as it is in most vehicle applications, any addition of heat to LNG will cause evaporation of natural gas. This evaporating natural gas will either expand, or if contained in a vessel, will increase the pressure within that vessel. Vessels containing LNG must be equipped with pressure relief valves to release fuel in order to prevent the rupture of the vessel.

Natural gas has a flammability range between about 5% and 15% by volume of natural gas in air. This means that concentrations of natural gas below 5% do not contain enough fuel to support combustion, and concentrations above 15% do not contain enough air to support combustion. This should be kept in mind when considering potential for ignition in the event of an LNG leak or natural gas release. The flammability range combined with the tendency for gases to disperse, especially gases which are lighter than air as natural gas is above -160°F, lead to a low likelihood of large LNG fires or explosions. Because natural gas is lighter than air, there is a potential for natural gas to collect near ceilings in hazardous concentrations if released inside a building.

One of the most important characteristics of LNG to consider when addressing its safety is temperature. At atmospheric pressure, saturated LNG is -260°F. This temperature will increase as the pressure increases, but in typical LNG vehicle applications the saturation temperature will not exceed -130°F. Fuel at these temperatures has the potential to cause severe cryogenic burns. Even indirect contact with the fuel through non-insulated piping or other fuel carrying equipment can be hazardous.

Keeping in mind the characteristics of LNG is important to avoid hazardous incidents while operating LNG vehicles. Until recent years, LNG had a poor safety image as a result of one accident. In 1944, a tank at a large bulk storage facility ruptured and caused a fire. Following that accident, safety codes were written to prevent future accidents. As long as the safety codes are adhered to, LNG can be safe for vehicle use. For the past several decades, the LNG industry has had significantly fewer accidents than conventional fuel refining and distribution facilities. For further information on the 1944 incident and two other incidents attributed to LNG see "A Brief History of U.S. LNG Incidents" at: http://www.ch-iv.com/lng.

Resources:

Murphy, M., Motor Vehicle Fuels: Properties and Specifications, Battelle, 2000.
CH IV Corp., Introduction to LNG Safety, CH IV Corp., 2000.
Murphy, M., Ketola, H., Raj, P., Clean Air Program: Summary of Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuel, FTA, 1995.

LNG Codes and Standards

Based on knowledge of LNG characteristics and the experiences of the LNG vehicle industry several codes and standards have been developed to provide guidelines for the design, production, and modification of LNG vehicles, fueling facilities, maintenance areas, and parking structures. These standards provide an important independent reference to help assess the safety and reliability of equipment designs and facilities modifications. Although only a brief introduction to these standards is presented here, further examination of these and all applicable standards is strongly suggested. Also, please monitor for updates of these codes that are released every few years or as new issues come up and are included in the codes.

NFPA 57, NFPA 59A, and SAE J2343 are the primary codes and standards that apply to LNG. These standards are not necessarily required by law. Organizations such as NFPA (National Fire Protection Association – www.nfpa.org) and SAE (Society of Automotive Engineers – www.sae.org) create these standards as guidelines, but they are only enforceable as law if a particular state or local government adopts them. Certain states such as Texas and California have developed their own codes[12], though they often have similarities with the standards discussed earlier. It is important to know what code if any is enforceable in your area. Even if

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[12] Railroad Commission of Texas, *Regulations for Compressed Natural Gas (CNG) and Liquefied Natural gas (LNG)* Available at: http://www.rrc.state.tx.us/tac/16ch13.html

California Code of Regulations, Department of the California Highway Patrol (CHP) Title 13, Division 2, Chapter 4, Article 2, Compressed and Liquefied Gas Fuel Systems. Available at: http://ccr.oal.ca.gov/

no codes are enforceable in your area, consideration should be given to specifying that vehicles, fueling stations, and associated structures to conform with at least one of the standards described earlier. Also, the codes officials in your area will often have the final say for all buildings and operating facilities. This is why it is so important to include these officials and fire marshals in planning and execution of your LNG operating program. Following the relevant codes is the key to safety. The important thing to gain from codes is an understanding of the total system approach.

NFPA 57 Liquefied Natural Gas (LNG) Vehicular Fuel Systems Code, 1999 Edition

NFPA 57 is a key standard associated with LNG vehicles and fueling facilities. It includes sections on vehicle fuel systems, fueling facilities, tank installations, fire safety, and marine vessels powered by LNG. The fuel systems section describes qualifications associated with the primary components associated with the fuel system. The fuel systems section also contains details regarding installation requirements for fuel system components. The fueling facilities section covers a variety of topics including dispensing systems, relief valves, and electrical equipment. The requirements for LNG storage in NFPA 57 only apply to containers of less than 70,000 gallons. Larger containers must adhere to the requirements of NFPA 59A. The next edition of NFPA 57 is expected in 2002.

NFPA 59A Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG), 2001 Edition

NFPA 59A details the guidelines for design and operation of large LNG facilities. Although the requirements for storage containers will not be applicable to most fleet operations, the guidelines for LNG transfer, piping systems, and vaporization facilities will be relevant. There are also general guidelines for fire protection, safety and security that should be considered. An update of NFPA 59A is not expected until 2004.

SAE J2343 Recommended Practices for LNG Powered Heavy-Duty Trucks, issued January 1997

This document profiles recommended practices for design, construction, operation, and maintenance of LNG trucks, though most practices can be applied to all medium- and heavy-duty vehicles. It includes sections on component construction and design, operation procedures and maintenance guidelines. This document provides a useful resource, especially for operators of LNG vehicles, to become aware of the standard practices within the industry.

Other Codes That May Be of Concern

The following list of codes may also apply to an LNG installation:

NFPA 30	Flammable and Combustible Liquids Code
NFPA 30A	Code for Motor Fuel Dispensing Facilities and Repair Garages
NFPA 70	National Electrical Code
NFPA 88B	Standard for Repair Garages
NFPA 90A	Standard for the Installation of Air Conditioning and Ventilating Systems

NFPA 91	Standard for Exhaust Systems for Air Conveying of Vapors, Gases, Mists, and Noncombustible Particulate Solids
NFPA 101	Life Safety Code
NFPA 325	Guide to Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids
NFPA 496	Standard for Purged and Pressurized Enclosures for Electrical Equipment
NFPA 497	Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas
UFC	Uniform Fire Code (www.icbo.org)
UBC	Uniform Building Code (www.icbo.org)
UPC	Uniform Plumbing Code (www.icbo.org)
UMC	Uniform Mechanical Code (www.icbo.org)
CFR	Code of Federal Regulations (www.access.gpo.gov/nara/cfr)

Potential Hazards Associated with LNG

Like any fuel or any new vehicle technology, there are potential hazards. As long as users are aware of these hazards they can be accounted for in vehicle and facility design. The following material describes the potential hazards that must be considered when using LNG.

Ignition Sources – It is important to eliminate ignition sources from areas where LNG vapor may rise, such as ceilings. There are two main types of ignition sources: hot sources and sparks. There are many types of hot sources. They include (but are not limited to) flames (including open flame heaters), engines, cutting and welding equipment, furnaces, heating equipment, and pilot lights. Sparks can be generated from such sources as electric hand tools, electric switches, ceiling fans, computers, and thermostat switches. Sparks produced from static electricity can come from such sources as motors, ungrounded refueling nozzles, and people. Also, facility wiring can be an ignition source and it is generally necessary to modify the wiring in an LNG facility to meet stricter fire code standards.

Contact with Fuel – As stated previously, LNG is a cryogenic liquid (i.e. below -117 °F) with a boiling point of approximately -260 °F. Because of the extremely cold temperature of LNG, personal injury will result if one comes into contact with LNG liquid, LNG vapor, or cold surfaces of pipes or other equipment containing LNG. Contact by any of these three means may result in cryogenic burns. Cryogenic burns result from the rapid freezing of tissue upon contact with the cryogenic source.

Although cryogenic burns from LNG vapor are usually not as severe as burns from direct contact with LNG liquid or a cold surface, the burns will generally affect a greater area of skin. In cases where cryogenic burns do not occur from LNG vapor exposure, less severe injuries such as frostbite or hypothermia are possible.

Materials and Compatibility – People are not the only things that can be affected by cryogenic liquids like LNG. Materials of equipment and structures may also be affected by LNG. Because low temperatures may affect the characteristics of certain materials, care must be taken to make sure that equipment and materials are not adversely affected under cryogenic conditions. Material properties such as ductility, tensile strength, and impact strength may be affected by cryogenic conditions. For many metals, tensile strength increases at low temperatures but ductility and impact strength will decrease, making the material brittle and easy to crack or shatter.

Listed below are some materials that can generally be used (or not used) under cryogenic conditions. Note that the materials listed include only some of (and not all of) the materials that are suitable (or not suitable) for cryogenic use.

> ***Materials suitable for cryogenic use*:** aluminum, copper, brass, nickel, lead, austenitic stainless steels, inconel, invar, Kel-F, epoxies, fiberglass, silver, gold, indium, cotton, polyester, wool; wood (short term use), leather (short term use), and Teflon (short term use)
>
> ***Materials not suitable for cryogenic use*:** polyethylene, polypropylene, rubber, carbon steels

If in doubt, ask the manufacturer of the equipment or consultants whether the material (or equipment) is suitable for cryogenic use.

Asphyxiation – There are few health hazards associated with LNG. The ordinary dangers of LNG from a health perspective are from cryogenic burns, hypothermia, lung damage (due to the inhalation of cold LNG vapor) and the possibility of asphyxia. To prevent asphyxia, gas detectors should be installed in areas where LNG or LNG vehicles are stored. In most outdoor leak situations, asphyxia will not be a problem. However, in an enclosed area with little ventilation, a large LNG leak may cause conditions to be sufficient for asphyxia to occur.

Vaporizing LNG – LNG does not have the same pressure issues associated with it as CNG, which is stored at high pressure. As a cryogenic liquid, there is always potential for LNG to vaporize in a contained volume, if it is allowed to warm to ambient temperature. This can cause pressure to build to dangerous levels. To prevent rupture of tanks or piping systems, any space where LNG may be trapped and vaporize should be protected by a pressure relief valve.

Resources:
SAIC, Introduction to LNG Vehicle Safety, GRI-92/0645, 1992.
Murphy, M., Ketola, H., Raj, P., Clean Air Program: Summary of Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuel, FTA, 1995.
CH IV Corp., Introduction to LNG Safety, CH IV Corp., 2000.

Vehicle Specifications

When vehicles are ordered or designed, they should be specified with at least a minimum level of safety characteristics. In addition to safety features designed into the vehicle, the vehicles must be operated and maintained in a safe manner in order to avoid hazardous incidents. The following material highlights the major vehicle related safety features and practices that are necessary to safely operate LNG vehicles.

For safety purposes, vehicles should be specified to adhere to all applicable codes and standards. This includes any enforceable state or local codes that may apply in your area. LNG vehicles should also be specified with the performance characteristics to perform their intended tasks adequately. This increases safety by preventing the vehicles from being regularly pushed to their performance limits. Using vehicles in a more rigorous manner than they were designed for decreases reliability and can compromise safety. Additional information on specifying vehicles is included in **How Do We Get Started?**

Pressure Relief – Pressure relief valves are a major safety feature of LNG vehicles. These valves are designed to prevent over-pressurization of the LNG fuel system. LNG liquid that is trapped between two valves in a piping system will warm and start to vaporize. The pressure in the pipe will increase causing the pipe to possibly burst (due to high pressures). A burst pipe may cause the pipe to act as "shrapnel" and could severely injure a person. Pressure relief valves should be connected at each fuel tank and any section of piping in which LNG could be trapped and vaporize. The specification of LNG pressure relief valves should include the requirement that they conform with applicable design codes.

Gas Detection Systems – Since LNG fuel is not odorized, humans cannot detect its vapors. Therefore, LNG vehicles should be equipped with gas detection systems, which use both audible and visual alarms to notify drivers, passengers and any other individuals that may be on or near the vehicle of the release of natural gas. It is important to take the time to understand how these systems work and what they detect.

Fire Detection and Suppression Systems – Fire detection and suppression systems are also often installed on LNG vehicles. These systems are typically designed to detect fires on-board the vehicle and initiate appropriate countermeasures such as interrupting flow of fuel to the engine, or releasing fire suppression chemicals. Like gas detection systems, these systems also typically activate both visual and audible alarms. These types of systems are typically not required by standards, but may be specified by vehicle users. Fire detection and suppression systems are most often used aboard buses and other passenger vehicles.

Protection of Fuel Tanks and Other Vehicle Components – In many cases, LNG vehicles are designed with shields to protect fuel tanks and other potentially vulnerable vehicle components from minor impacts due to rocks or other debris. These components may also be protected by locating them within the frame rails of the vehicle or by using other structural protection such as cages. For safety purposes, some manner of protecting key vehicle components should be included in the vehicle specifications.

Resources:

Stephens, D., Herridge, J., Gifford, M., Reference Guide for Integration of Natural Gas Fuel Systems, GRI-02/0013, 2002.
NexGen Fueling Training Class and CD-ROM, www.nexgenfueling.com.
SAE, Recommended Practices for LNG Powered Heavy-Duty Trucks, SAE J2343, 1997.
California Highway Patrol, Standards for Liquefied Natural Gas, CCR, Title 13, Article 2, Section 935, 1997.

Vehicle Operation and Maintenance

After the vehicles have been designed, built, and delivered, there are many important elements involved in keeping LNG vehicles operating safely. The following material presents the major facets of safe LNG vehicle operation and maintenance. Other information sources and training should also be consulted for further information regarding these issues as well as other potential issues.

Accidents – It is important that drivers know the proper procedures to follow in the event of an accident involving an LNG vehicle. Accidents may cause fuel systems to leak or otherwise prevent vehicles from being operated safely. Training for drivers should be considered so that they can perform inspections of vehicles in the event of accidents. Drivers should also be aware of the safety features of the vehicle such as shutoff valves and pressure relief valves.

Preventive Maintenance Inspections – Preventive maintenance inspections are a critical element of safely maintaining LNG vehicles. Regular inspections allow potential vehicle problems to be recognized before unsafe conditions develop. Although inspections may not be able to completely prevent vehicle breakdowns, they should be able to reduce the amount of unscheduled vehicle downtime. Standard industry practices call for vehicles to be inspected every month to month and a half. Often inspections are performed at the same time as other recurring maintenance operations such as oil changes. Vehicle manufacturers and/or maintenance manuals should be consulted when setting the particular inspection intervals for your vehicles.

Maintenance Manuals – It is important that the appropriate maintenance manuals accompany the vehicles and that these manuals are consulted regularly. Well-written manuals should make the users aware of the necessary safety precautions that should be taken when performing maintenance on LNG vehicles. Procedures for defueling the system and the proper maintenance environment should be described. In addition, the reasoning behind safety precautions and a general safety approach to LNG vehicle maintenance should be explained. Maintenance personnel should consult these manuals regularly and should follow their suggestions for inspection intervals and repair procedures.

Leak Detection – Vehicle leaks can originate from many different areas. By using a soap solution or handheld gas detector, leaks may be pinpointed. Note that a match, flame, or other ignition source should *never* be used to detect a leak.

Defueling – The fuel system is always under pressure during normal operation. In order to perform maintenance safely, it is often necessary to reduce the pressure within the fuel system to atmospheric pressure. The pressure within the fuel system is typically reduced by removing fuel from the system. There are specific procedures that should be followed when defueling a vehicle. Incorporating shutoff valves to isolate portions of the fuel system and bleeder valves to remove fuel from the system into the design of the system will simplify the defueling process.

Additional Vehicle Safety Considerations – There are many other vehicle safety concerns that should be addressed when vehicles are specified as well as during vehicle operation and maintenance. It is important to take advantage of as many resources as possible in order to become your own expert in vehicle safety. Additional resources are listed in the subsection **Where Can I Find More Answers?**

Resources:

Stephens, D., Herridge, J., Gifford, M., Reference Guide for Integration of Natural Gas Fuel Systems, GRI-02/0013, 2002.
Freidman, D., Malcosky, N., Clean Air Program: Liquefied Natural Gas Safety in Transit Operations, FTA, 1996.

Fueling Facilities

LNG fueling stations should be designed with many safety features. These features are typically designed to prevent pressure buildup, unsafe fuel releases, and exposure to cryogenic materials. The implementation of these features and the ability of on-site personnel to properly respond to emergency situations will minimize the potential for costly or dangerous incidents.

Codes and Standards – Fueling facilities should be specified to adhere to all relevant codes and standards as well as applicable regulations. It is important to develop relationships with the local authority having jurisdiction and to learn what codes are applicable at your location. In many cases, the edition of a standard, which has been adopted by a state or locality, is not the most recent version of that standard. In these cases, the adopted version of the standard must be adhered to in order to be in compliance with local regulations, even if that standard is outdated.

Pressure Relief – As in vehicle fuel systems, the potential exists in fueling systems for LNG to vaporize while trapped between valves in piping. Pressure relief valves should be connected to any section of piping within an LNG fueling facility in which LNG could be trapped. Care should also be taken to be aware of where these relieved vapors are released. Some relief valves may vent directly while others may be routed through vent piping. It is important that fuel vapors are released from a position that allows the fuel to freely escape to the atmosphere without coming near an ignition source or collecting anywhere unintentionally.

Combustible Gas and Fire Detection – The fueling facility should also have detection devices that can detect gas leaks and/or fires. Combustible gas detectors are used to detect any release of natural gas. Flame detectors and smoke detectors are typically used to detect fires. In addition, both high temperature and low temperature detectors may also be used to detect flames or LNG leakage. Detection devices will be discussed in further detail in *Hazard Detection Equipment* later in this subsection. Figure 2-23 shows fire suppression chemical storage at an LNG fueling station, and Figure 2-24 shows the alarm strobes from a combustible gas detection system inside a maintenance facility.

Figure 2-23. Fire Suppression Chemical Storage at an LNG Fueling Station

Figure 2-24. Combustible Detection System Alarm Strobes Above Door Opening

Signage and Labeling – A facility should also have proper signage to alert others of the potential hazards associated with LNG use. There may be signs alerting visitors and personnel that LNG is being used on-site. There may also be "no smoking" signs as well as signs warning against the use of flame, heat, or spark inducing equipment. These signs would also include warnings to turn off all engines before fueling. Figure 2-25 provides an example of some of the signage and labeling at an LNG fueling station.

Figure 2-25. Signage at an LNG Fueling Station in Austin, Texas

Sources of LNG Leaks – There are many different possible sources of leaks in an LNG fueling facility. When LNG leaks, it cools the ambient air and a visible cloud of water vapor may form. Some leaks may require a system shut down while others may be isolated and repaired without a system shut down. Among the most likely sources of an LNG leak are the following:

- Valves
- Transfer Hoses / Flexible Hose
- Welds
- Flanges
- Fittings
- Threaded Connections

If there is a leak, it should be determined whether the leak may be stopped (for example, by tightening of a fitting) or whether the source of the leak needs to be replaced (cracked or damaged fittings). Any damaged part should be replaced. Maintenance inspections should be done periodically to detect and mitigate any corrosion, damage, or leaks that may exist in the system. Maintenance schedule guidelines should be provided by the manufacturers and installer of the fueling facility.

Possible Ignition Sources – It is important that all possible ignition sources be removed from the area surrounding a fueling station. Specific guidelines exist for locating electrical devices near fueling facilities. NFPA 57 is a starting point for such guidelines but relevant electrical codes should also be consulted. Other possible ignition sources, such as flame heaters or electric motors, should not be located near fueling facilities. In addition, fueling facilities should not be located near high voltage lines.

Fueling Equipment Inspection – LNG nozzles and hoses need to be inspected periodically. It is recommended that the fueling equipment be inspected every day. Inspection of the fueling equipment will include the nozzles, fuel hoses, and any screws, nuts, bolts, or connections. Manufacturers should be consulted for inspection procedures.

Fueling Procedures – While fueling, certain precautions should be taken. First, the vehicle ignition should be turned off. Next, the vehicle should be properly grounded to prevent static electricity build up (this is many times done through the fueling hose). No smoking should be allowed, and there should be no open flames, spark-producing equipment, or ignition sources in the vicinity of the fueling station/area. To protect personnel from injury, proper clothing and protection equipment should be worn at all times. Personnel should receive specific training on the proper procedures for fueling LNG vehicles before they are assigned to do so.

Indoor Fueling – When fueling is performed indoors, there are many special considerations for dealing with fuel releases and providing proper ventilation. In general, however, the relevant issues regarding indoor fueling overlap with the issues involved in indoor maintenance of LNG vehicles. For the most part, the considerations discussed in the following material such as methane detection equipment and ventilation, will also apply to indoor fueling facilities.

Resources:

Sui, N., Herring, J., Cadwallader, L., Reece, W., Byers, J., Qualitative Risk Assessment for an LNG Refueling Station and Review of Relevant Safety Issues, INEEL/EXT-97-00827 rev. 2, 1998.
Midgett, D.E., Best Available Practices for LNG Fueling of Fleet Vehicles, GRI-96/0180, 1996.
Freidman, D., Malcosky, N., Clean Air Program: Liquefied Natural Gas Safety in Transit Operations, FTA, 1996.
CH IV Corp., Introduction to LNG Safety, CH IV Corp., 2000.
Raj, P., Hathaway, W., Kangas, R., Clean Air Program: Design Guidelines for Bus Transit Systems Using Liquefied Natural Gas (LNG) as an Alternative Fuel, FTA, 1997.
Natural Gas Vehicle Institute – www.ngvi.org.

Maintenance and Parking Facilities

If your LNG fleet is to be housed or serviced in indoor garages and maintenance facilities, customized ventilation, monitoring, and personnel training will be required. Indoor maintenance facilities and garages housing LNG vehicles may need to have customized ventilation and monitoring systems installed, i.e., more ventilation than is required for gasoline- and diesel-fueled vehicles. Leak detection systems should be installed (e.g., methane detectors). Further information regarding the need for facility modifications is included in the following paragraphs.

Fuel Release Remediation – LNG vapor is heavier than air when its temperature is less than -160 °F and the surrounding air is at ambient temperatures (60 °F). Above -160°F, LNG will be lighter than air. Therefore, during an LNG leak, LNG vapor may initially accumulate in low areas but will rise once it is sufficiently warmed.

Because of LNG vapor's tendency to rise, appropriate measures need to be implemented when designing an LNG maintenance or vehicle storage facility. For instance, all possible ignition sources should be removed or located at distances that prevent them from igniting flammable mixtures. This will include locations near likely LNG leak sources and at locations where LNG may pool (cold LNG) or rise (warm LNG). NFPA 57 and 59A, may be used to obtain general recommendations on facility design and locations of equipment.

As long as maintenance facilities and parking structures are separate from fueling facilities, the vehicles themselves should be the only possible sources of LNG leaks. When maintenance and parking facilities are integrated with fueling facilities, the fueling facility components will be additional possible sources of LNG leaks. The potential leak sources for fueling facilities are detailed earlier in this subsection.

Ventilation – An indoor maintenance facility or enclosed parking structure should have adequate ventilation. Having proper ventilation is necessary to prevent flammable mixtures from accumulating and to prevent an asphyxiating atmosphere. In general, gas concentration should not be allowed to be greater than one-fifth of the lower flammability limit (NFPA 57). Industry practices typically specify 6 air changes per hour. The ventilation system is often integrated with the hazard detection system. When high gas concentrations are reached, the ventilation system increases air circulation. For emergency situations, industry practices generally specify 10 to 12 air changes per hour.

Hazard Detection Equipment – In any LNG facility, there will be a need to have detectors available that will warn if any hazards are present around the facility. A detection system should be set up to warn personnel if hazardous conditions are present and if emergency response procedures need to be initiated. Below are the types of detectors generally present at an LNG facility and descriptions of each.

> Combustible Gas Detectors – Combustible gas detectors are devices that sense the presence of fuel vapors in the air. They relate the concentration of vapors to flammability limits and do one or two of the following. The detector warns (through an alarm) that gas vapor levels are too high and/or automatically shuts down the equipment.
>
> Flame Detectors – A flame detector is a device that detects thermal radiation. They resemble small television cameras and detect heat by sensing either ultraviolet (UV) or infrared (IR) wavelengths. False alarms may be triggered by lightning, welding arcs, and sunlight reflecting off windshields. To minimize false alarms, both UV and IR detectors should be used and the view areas should overlap in a way such that automatic shutdown will not occur unless sensed by both detectors. Therefore, if only one detector goes off, this will alarm personnel but will not shutdown equipment if the alarm is a false alarm.
>
> High Temperature Detectors – High Temperature detectors sense either a set high temperature or a rapid temperature increase. They contain fusible links that melt at high temperatures, activating an alarm. They are placed in areas of high fire risks. The alarm may be set to automatically shut down equipment and/or activate fire suppression equipment.

Low Temperature Detectors – Low temperature detectors are devices that sense LNG liquid or cold vapor releases through the use of devices like thermocouples or resistance temperature devices. They are generally placed in low-lying areas where spills and cold vapor may accumulate.

Smoke Detectors – Smoke detectors sense smoke from smoke producing fires. They are usually used with high temperature detectors. It should be noted that LNG fires do not produce a lot of smoke. Therefore, smoke detectors are used primarily to sense non-LNG fires.

Signage/Placards – Signs and placards should be placed around the LNG storage, maintenance, and fueling areas warning of LNG use, hazards, or precautions that need to be taken by personnel. Listed below are some of the things that may be listed on signs/placards.

- LNG in Use
- Flammable
- No Smoking
- No Open Flames
- No Hot Surfaces
- No Sparks (Including Any Tools That Generate Sparks)
- Keep All Ignition Sources Away
- Do Not Operate Welding or Cutting Tools
- Do Not Operate Non-Approved Electrical Equipment
- Cryogenic Substance

Resources:

SAIC, Introduction to LNG Vehicle Safety, GRI-92/0645, 1992.
Midgett, D.E., Best Available Practices for LNG Fueling of Fleet Vehicles, GRI-96/0180, 1996.
Freidman, D., Malcosky, N., Clean Air Program: Liquefied Natural Gas Safety in Transit Operations, FTA, 1996.
CH IV Corp., Introduction to LNG Safety, CH IV Corp., 2000.
Raj, P., Hathaway, W., Kangas, R., Clean Air Program: Design Guidelines for Bus Transit Systems Using Liquefied Natural Gas (LNG) as an Alternative Fuel, FTA, 1997.

Transporting LNG

LNG is typically transported to the fueling station by truck, similar to conventional vehicle fuel distribution. LNG tanker trucks would be unlikely to rupture, because LNG is transported in a double-walled tank that is stronger than the tanks used to deliver other fuels. The likelihood of a rupture of an LNG container is small unless the pressure relief equipment or system failed completely or an unusual combination of events were to take place (e.g., loss of insulation, along with obstruction of the venting and pressure relief system).

Personal Protective Equipment

When fueling an LNG vehicle or coming into contact with equipment containing cryogenic liquids like LNG, personnel should use proper protective equipment to prevent injuries. It is recommended that the following protective equipment and recommendations be used when fueling LNG vehicles or coming into contact with cryogenic equipment:

- Safety glasses/goggles
- Full face shield (not just glasses)
- Full length gloves (loose fitting, plastic or rubber insulated)
- Full length protective apron
- Heavy footwear (boots)
- Cuffless trousers (without pockets if possible)
- Long sleeve shirt
- All clothing should be non-permeable
- No jewelry should be worn

Clothing should be non-permeable and loose fitting. Gloves should not be tucked into the sleeves and the trousers should be cuffless and covering (over) the boots. No skin should be exposed. All clothing should be worn so that no gaps or folds (which may trap LNG if spilled) are present. Jewelry (which may freeze onto the skin) should be avoided. Figure 2-26 shows a fueler with appropriate safety equipment.

Figure 2-26. LNG Fueler Wearing Appropriate Protective Equipment

Resources:

Raj, P., Hathaway, W., Kangas, R., Clean Air Program: Design Guidelines for Bus Transit Systems Using Liquefied Natural Gas (LNG) as an Alternative Fuel, FTA, 1997.
Freidman, D., Malcosky, N., Clean Air Program: Liquefied Natural Gas Safety in Transit Operations, FTA, 1996.
CH IV Corp., Introduction to LNG Safety, CH IV Corp., 2000.
AGA, Introduction to LNG for Personnel Safety, X08614, 1986.

Emergency Response

Even when employees are well trained, facilities are well designed, and proper safety procedures are followed, unforeseen accidents may occur. Events such as natural disasters, fires, power failures, or simple human error may present the facility with an emergency situation. If the emergency is not handled correctly, lives may be lost, property may be damaged, and lasting damage to the environment may occur. A good emergency response plan will completely contain the situation and bring things back to normal as soon as possible.

For a typical fleet facility, there are three main domains of concern with regard to emergency response – fuel storage, fueling facilities, and vehicle operation and maintenance. The emergency plan must incorporate all three areas to be effective. An emergency plan itself should have the following key elements:

- **Evacuation Procedures** – The evacuation procedures identify the evacuation routes, how personnel will be accounted for in the event of an accident, where personnel will meet after the evacuation, responsibilities of key employees during an accident, and any requirements dictated by local, state, or federal law.

- **Plan Coordination** – The plan coordination is the process of documenting the emergency response. Its focus is on identifying who needs to be involved in the emergency response planning and making sure the plan has been reviewed by those people and that their input has been included. All involved should understand their roles and agree to them. In many cases, it can be helpful to have individuals sign off on their responsibilities to ensure that they have “bought into” the plan. The plan should be updated as needed.

- **Plot Plan** – The plot plan identifies areas that may be affected due to an accident, environmental factors, and response routes. It is a guide to the emergency response procedure. It should include action plans for addressing emergencies that may occur within all three of the major domains of concern.

- **Available Equipment** – The proper equipment should be available to appropriately handle emergency situations. The equipment may include firefighting equipment, medical and/or first aid equipment, self-contained breathing apparatus, and wind speed and direction indicators. If employees need to use the equipment, then training should be provided.

- **Emergency Numbers** – Emergency numbers should be readily available and posted near all phones in fueling and maintenance. The numbers should include any facility personnel that need to be contacted including any key organizational contacts, plant management, emergency personnel, local officials, healthcare officials, media contacts, community awareness and response groups, and national assistance organizations.

- **Material Safety Data Sheets (MSDS)**[13] – It is important to have the appropriate Material Safety Data Sheets (MSDS) on-site. An MSDS for LNG will list the properties of the fuel and other relevant information. Included on these sheets are such things as the product identification, hazardous ingredients, physical data, fire and explosion hazard data, health hazard data, reactivity data, spill or leak procedures, special protection information, or any special precautions that need to be taken. The sheets aid workers in knowing the safety, fire, and health implications of LNG as well as steps that should be taken in case of an emergency. The sheets can also aid emergency personnel who may be on-site. The sheets should be readily accessible.

- **Employee Training** – Training of employees is probably the most important aspect of safety. If employees are not trained properly in the handling and/or operation of LNG and LNG vehicles, safety will be compromised and in cases of emergency, poor or possibly dangerous decisions will be made. Any employee that will be either directly using the LNG fuel and/or vehicle or making decisions on LNG vehicles and/or fuel use needs to be trained. This includes fuel attendants, mechanics/ maintenance workers, vehicle operators, and any supervisors and managers of an LNG facility. The need for training is obvious for mechanics/maintenance workers, fuel attendants, vehicle operators, being that they directly use, operate, and maintain LNG vehicles and facilities. However, management and supervisors also need to be trained because they will be responsible for decision-making in terms of safe operating procedures, emergency procedures, and possible in-house training. Therefore, they also need to know the properties and safe handling/use of LNG.

- **Testing and Evaluating Response** – The emergency response plan should be tested and evaluated periodically to ensure that personnel are able to quickly and correctly respond to an emergency. This may include drills/mock exercises, tests of alarms, tests of equipment, and evacuation procedures. The evaluation should be documented and corrective actions should be taken if necessary. It is best to include local agencies and emergency response organizations within your community in the testing process. It will give all involved an idea of what the hazards are and what may go wrong. Personnel can also gain feedback from the agencies on better approaches to the emergency response plan, better equipment, or better training

[13] Atallah, S., Saxena, S., Gustafson, R., Risk Management Plan Guideline for LNG Vehicle Fueling Stations, GRI-98/0245, 1998, Appendix B shows a sample MSDS for LNG.

Resources:

Atallah, S., Saxena, S., Gustafson, R., Risk Management Plan Guideline for LNG Vehicle Fueling Stations, GRI-98/0245, 1998.
Brown, B., A Model Emergency Response Plan, American Society of Safety Engineers, 1995.
Introduction to LNG Safety, 2000, CH IV Corp.
Raj, P., Hathaway, W., Kangas, R., Clean Air Program: Design Guidelines for Bus Transit Systems Using Liquefied Natural Gas (LNG) as an Alternative Fuel, FTA, 1997.
Freidman, D., Malcosky, N., Clean Air Program: Liquefied Natural Gas Safety in Transit Operations, FTA, 1996.

Safety and Training

Safety and risk considerations of any fuel for transportation are voluminous, especially if it is new to the facilities and operation. It is important to ensure that personnel are trained to know the properties of LNG and to know proper safety procedures pertaining to LNG fuel and vehicle use. Personnel involved in the fueling and/or use of LNG vehicles, including but not limited to mechanics, drivers, supervisors, engineering staff, and fueling personnel should receive training in the proper use of LNG. This training may be obtained from supplier schools, original equipment manufacturers (OEM), mechanic schools, and internal training. LNG safety procedures should be integrated into the existing facility standard operating procedures (SOP). There are several aspects of LNG vehicle operation that need to be considered from a safety training perspective:

- Personnel
- Vehicles
- Fueling facility
- Maintenance facility
- Vehicle storage facility and any other facility where a vehicle may be housed
- Operation of each of these facilities
- Operation of the vehicles
- Leak detectors.

NFPA 57 *Liquefied Natural Gas (LNG) Vehicular Fuel Systems Code*, which was discussed earlier, recommends that personnel handling and dispensing LNG should be trained in proper handling and operating duties and procedures. Prior to delivery of the LNG fuel, a general information session provided by vendor representatives and company emergency responders should be held for all on-site staff. Then separate training programs should be conducted depending upon the roles of personnel, starting with those closest to the new fuel, such as fuelers, vehicle operators, dispatchers, on-site protective services personnel, medical staff, and emergency responders. Emergency practice drills should also be conducted. Then a short course should be scheduled for support staff, like security personnel, managers, and administrative managers.

The most important steps to ensuring safety and limiting risk are to provide comprehensive training for personnel working around or using LNG and to ensure that all other personnel are aware of the fuel's hazards if mishandled. LNG as a vehicle fuel will be new to your operation so training and experience in using the new fuel are important to ensure initial and long-term safe operations. Because using LNG involves safety practices that are intuitively different from the practices associated with conventional fuels, fleet managers should pay special attention to all aspects of transportation operations during the early stages of implementation.

Fleet operators may want to provide certification training for critical staff, and emergency responders. Training priority should be given to those personnel who may have direct contact with the vehicle or the fuel, including vehicle operators, fuel system maintenance personnel, fuelers, fire fighters, medics, and inspectors. In addition, certain equipment may require certification such as hazard detectors, fire extinguishers, ventilation systems, on-site fuel storage tanks, as well as cryogenic pipes, hoses, connectors, and valves. Even if certifying equipment and personnel is not required in your area, it can help to alleviate any concerns individuals may have about using LNG, both within your organization and in your surrounding community.

The primary training should focus on safety issues related to storage facilities for LNG-fueled vehicles, storage tank placement, hazards, proper use of fueling equipment, access routes for fuel delivery trucks, and changes in on-site traffic patterns. These safety issues, though quite common to personnel using gasoline or diesel fuels, need to be emphasized specifically for LNG so complacency does not replace good judgment. Periodic retraining should be conducted, adapting training courses and directions to personnel roles, reactions to site conditions, questions about new risks, and work assignment concerns. Eventually, you will need to determine how to integrate the new LNG-related topics into regular training schedules and plan to train incoming employees.

For drivers, fuelers, supervisors, maintenance technicians, and safety trainers, the most important safety aspects are the need for:

1. Awareness of the fuel's differences from gasoline or diesel among personnel who work around the LNG fuel (for example any fuel boil-off from out-of-service vehicles must be detected and managed)
2. Practice in safe handling procedures
3. Ongoing training in the use of safety equipment and recognition of warning devices

Personnel should be aware that bodily contact with the liquid fuel, cold metal, or cold gas could cause cryogenic burns (i.e., frostbite). Protective clothing should be required for personnel who may be exposed to LNG, including full-face shields and cryogenic gloves and aprons.

Here are additional suggestions and considerations for personnel safety and training topics, followed by a list of suggested safety information resources, and a summary of training needs by job category:

- **Fuel issues**—fuel compatibility; pressure venting issues; cryogenic hazards and risks; fuel vapor hazards; safety equipment; and warning devices (e.g., methane gas detectors must be installed to detect leaks, because odor-detecting agents cannot be added to LNG.)
- **Facilities maintenance and operations**—proper operation of the fueling station and island; required and/or recommended maintenance; safe vehicle storage; vehicle washing procedures; use of safety equipment; and procedures for responding to warning devices.

- **Vehicles maintenance and operations**—fueling procedure; normal operations on routes; preventive maintenance, and unscheduled repairs; response to accidents; use of safety equipment and proper reactions to warning devices.
- **Risk management plan**—fire and emergency response procedures for personal injury, vehicle collisions or failures, and incidents within facilities.
- **Training**—integrate LNG education into the existing program; require refresher courses at regular intervals; test for comprehension; decide who gets trained (drivers, supervisors, mechanics, fuelers); send appropriate personnel to training provided by the OEM suppliers; and investigate the availability of courses at technical colleges.

The topics which personnel need to be trained in by job category include:

- **Vehicle drivers**—LNG characteristics, changes in vehicle operation, vehicle-specific emergency responses.
- **Maintenance engineers**—LNG characteristics, maintenance and repair safety, emergency response, as well as vehicle and site-specific emergency responses.
- **Dispatchers**—LNG characteristics, general emergency response.
- **Parking attendants**—LNG characteristics, general emergency response.
- **Refuelers**—LNG characteristics, refueling safety, and emergency response.
- **On-site medical staff/first aid**—LNG characteristics, treatment of general injuries and cryogenic burns.
- **Security**—LNG characteristics, fuel-specific as well as general emergency response.
- **Safety inspectors (vehicle and facilities)**—LNG characteristics, site changes, refueling, maintenance and repair safety, safety equipment (e.g., fire extinguisher, hazard detectors, ventilation equipment).
- **Shop management**—all of the above.

Help in obtaining the certifications and training for alternative fueled vehicles is available from several institutions including: the Natural Gas Vehicle Institute, National Automotive Technicians Education Foundation/Automotive Service Excellence NATEF/ASE and National Alternative Fuels Training Consortium NAFTC. Although not always required by state regulations, a number of transit agencies and trucking fleets that operate alternative fueled vehicles have taken advantage of these training programs.

References:

Natural Gas Vehicle Institute: www.ngvi.com
National Automotive Technicians Education Foundation: www.natef.org
National Institute for Automotive Service Excellence: www.asecert.org
The National Alternative Fuels Training Consortium: naftp.nrcce.wvu.edu

Is LNG Readily Available?

As noted earlier, natural gas is abundantly available from both domestic and North American suppliers. At projected levels of consumption, natural gas supplies will meet U.S. demands for at least 60 years, with non-conventional supplies capable of providing an additional 200-year supply. There is significant LNG production capacity in the United States in addition to significant LNG transported here from outside the United States by large ships. Government forecasts suggest that LNG will be readily available for the foreseeable future and also suggest that its price is likely to remain competitive among transportation fuels.

In local terms, while a network of public natural gas fueling stations is developing for CNG, public LNG fueling stations are not yet available in most areas. In the near term, LNG will be best suited for fleet vehicles that return to a central facility for fueling, though this may change in the long-term if public LNG fueling stations become available. Such a network could develop in some areas if current efforts to build and distribute small-scale liquefaction plants are successful. One such network being developed in the western U.S. is the Interstate Clean Transportation Corridor (ICTC).

North American LNG Production and Distribution

Most LNG in the United States is produced at storage locations operated by natural gas suppliers and at cryogenic extraction plants (Figure 2-27) in gas producing states. In most cases, these suppliers produce LNG and store it for use during periods of high winter (heating) demand for natural gas. The process of adding natural gas from LNG (or other gaseous hydrocarbons) to the normal distribution lines during periods of high demand is known as "peak shaving". In a 1998 report by Zeus Development[14], 120 facilities in the United States were identified as producing LNG as part of normal operations. A handful of the large-scale liquefaction facilities in the U.S. provide LNG fuel for transportation uses (see the map below, Figure 2-29). These suppliers have capacities normally ranging from 50,000 to over 600,000 gallons per day. A fleet of 100 transit buses would be expected to use approximately 5,000 to 8,000 gallons of LNG fuel per day.

Current Availability vs. Potential Availability

It is estimated that about 7,566,000 gasoline gallon equivalent (GGE) of LNG are used annually within the U.S. for transportation fuel. As stated earlier, in the United States, 120 plants produce or store LNG as part of their normal operations. Of these, 59 generate LNG for peak shaving applications and seven plants sell LNG for motor fuel use. Consequently, there is a significant capacity in the United States for producing LNG that could be tapped for motor-fuel purposes if the market demand were to increase. In most of these cases, these plants can be readily shifted to LNG production if there were sufficient economic incentive. One of the major barriers is

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[14] Zeus Development, LNG Vehicle Markets and Infrastructure, GRI-98/0196, 1998.

available and reliable transportation to the fleet's site at a reasonable cost. Small-scale liquefaction, described in more detail below, may also add significant LNG motor fuel capacity in the future if commercially successful.

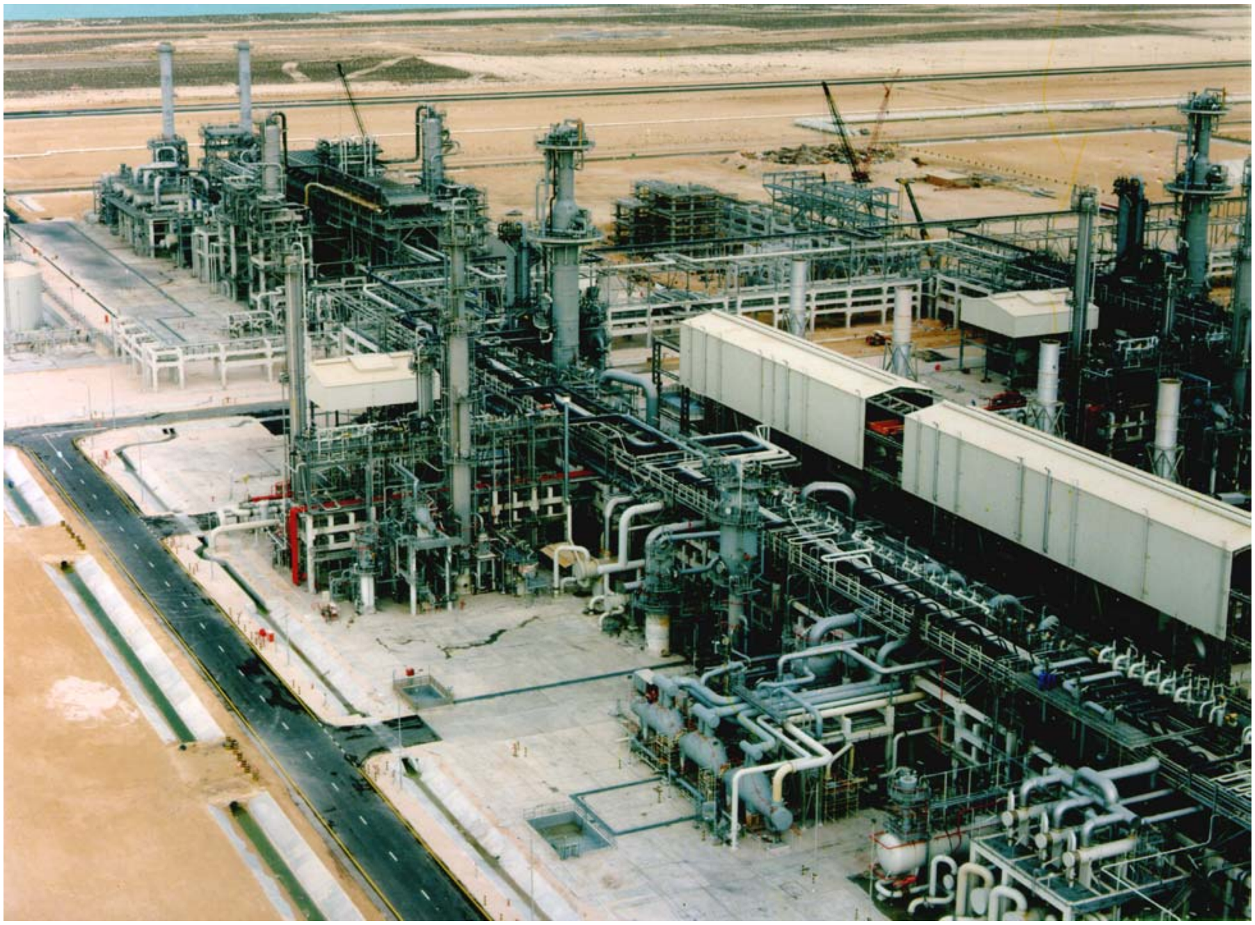

Figure 2-27. LNG Processing Facility

Figure 2-28. Bulk LNG Delivery to a Fuel Station

Bulk quantities destined for storage depots are shipped by railcars, barges, and ships carrying up to 30 million-gallon loads. LNG can be transported from the bulk storage depots to fleet facilities by trucks, which deliver roughly 10,000 gallons with small tank trailer-trucks (Figure 2-28). Most frequently, trailer-trucks are used to deliver LNG from the bulk depots to a fleet's fueling station(s), much like diesel or gasoline is delivered.

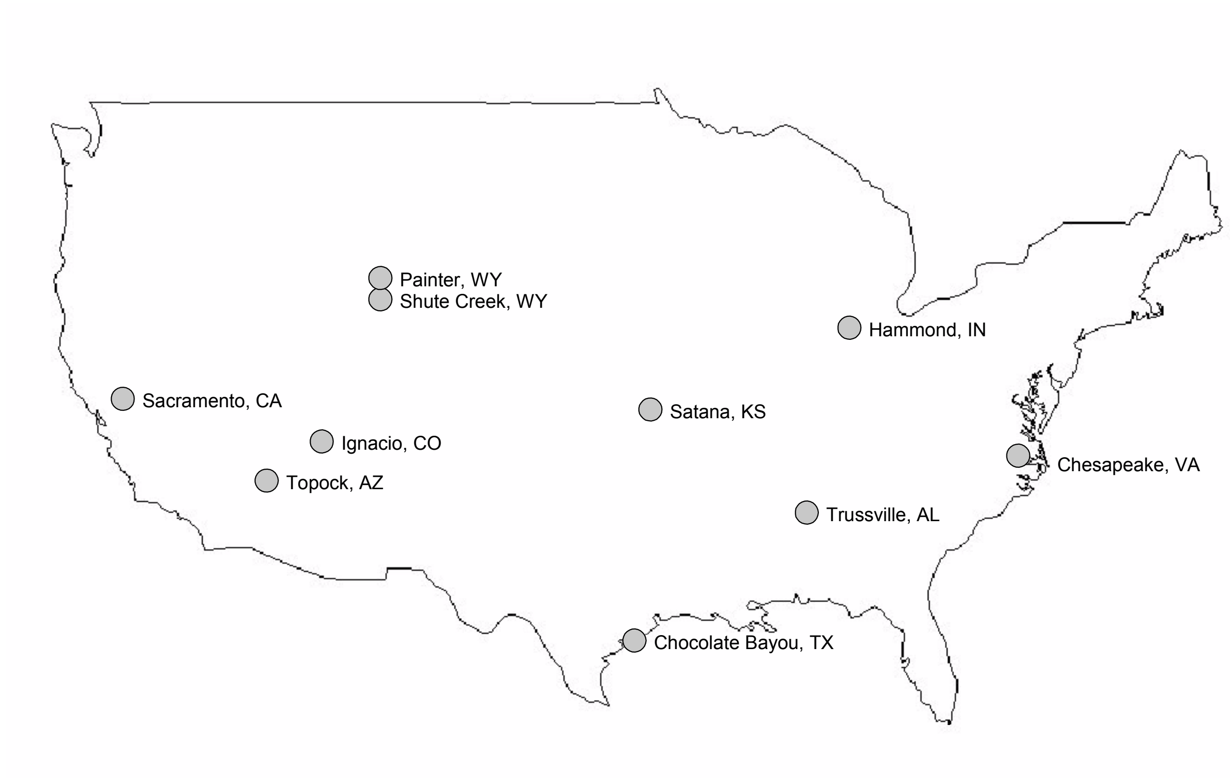

Figure 2-29. Locations of LNG Production Plants in the U.S.

LNG Motor Fuel Production Plants

Table 2-8 below summarizes the plants currently producing and selling LNG for motor vehicle use in the United States.

Table 2-8. Current Chemical Facilities Producing LNG for Transportation in the U.S.

Location	Type of Facility	Owner
Sacramento, California	LNG Plant	Quadren
Chocolate Bayou, Texas	Olefins Plant	BP
Painter, Wyoming	Nitrogen Rejection Unit	BP
Satanta, Kansas	Nitrogen Rejection Unit	Pioneer
Shute Creek, Wyoming	Nitrogen Rejection Unit	ExxonMobile
Ignacio, Colorado	Gas processing	Williams Energy
Hammond, Indiana	Peak Shaver	NIPSCO
Trussville, Alabama	Peak Shaver	Trussville Utilities
Chesapeake, Virginia	Peak Shaver	Columbia Gas
Topock, Arizona	LNG Plant	El Paso Natural Gas

Local Availability Issues

LNG is typically purchased directly from the producer by the load or a long-term contract. The transportation of the fuel is contracted separately from an LNG shipping company. JB Kelley is one example of a company that delivers LNG. Most operators purchase LNG in truckload batches of roughly 10,000 gallons delivered 2 to 4 times per week depending upon fuel usage. Transportation costs often make up a significant portion of the cost of LNG, and it is generally not economical to transport LNG farther than 500 miles in any direction from the LNG production location.

Sources of LNG

There are several different techniques for creating LNG. It is important to understand the source of your LNG and how the operations of that source could affect the availability of LNG. The current and potential means of LNG production are discussed below.

Peak Shaving Plants – Peak shaving plants are designed to create LNG so that it can be stored and reintroduced into the distribution network during peak demand periods. Peak shaving facilities have been used for many years to store natural gas for reinsertion in to the natural gas pipeline. The use of peak shaving facilities to provide LNG for vehicles has been occurring roughly as long as LNG vehicles have been in use. LNG produced at peak shaving facilities can be easily transported in double-walled tanker trucks to fueling stations for use in vehicles. Peak shaving facilities are generally reliable sources of LNG because their primary purpose is to store excess LNG. Peak shaving plants are one of the most common sources of LNG for vehicle fuel. The major barrier here is that it is not clear in most places if it is possible to sell LNG from these facilities because the facility and operation were paid for by the natural gas customers. Peak shaving facilities can also often be located far from operating LNG fleets.

Nitrogen Rejection Units and Other Industrial Plants – Nitrogen rejection units (NRUs) and other LNG producing industrial plants are another possible source of LNG for your fleet. NRUs liquefy natural gas in order to remove the nitrogen content. Other LNG producing industrial plants are typically designed for processing gas or petroleum products. LNG is essentially a by-product of these industrial processes, which are typically designed to accomplish other chemical processes, most often some form of gas separation. If you use one of these industrial facilities as your source of LNG, you should consider what priority will be placed on LNG production, how planned and unplanned shutdowns will affect fuel availability, and how reliable the facility will be at supplying fuel.

Small-Scale Liquefaction – As discussed earlier, transportation costs are often a significant portion of the cost of LNG. For this reason, significant research and development budgets are being spent to develop low cost “small-scale” LNG liquefaction plants that can be easily located near fuel usage sites. These plants are intended to be self-contained, skid-mounted and generate enough LNG to supply 2 to 4 average size fleets. One suggested strategy is to locate these plants at the junction of natural gas transmission and distribution pipelines (the so called “city gates”) where the pressure is dropped for local distribution, a change in pressure of 400 to 1000 psi. These plants use the “free” energy and cooling from the pressure drop to drive the liquefaction process. These types of facilities may also be located near stranded wells to allow liquefaction of stranded gas for transportation, or along some point of the pipeline. Small-scale liquefaction technology is near commercialization and demonstration plants are expected to be put in operation in California in 2002. Small-scale liquefaction plants could significantly reduce the transportation costs associated with most LNG applications.

Landfill Gas – Another potential source of LNG is landfill gas. Landfill gas consists of about 50% methane and 50% carbon dioxide (CO_2). However, trace amounts of water vapor, volatile organic compounds, and other contaminants are also present. The ability to convert landfill gas to LNG requires cleaning up the natural gas and then using small-scale liquefaction technology to produce the LNG. Technology is developing to economically separate and liquefy the methane content in landfill gas to make LNG. This technology is in its very early stages, but it is technology that may be a significant source of LNG in the future. Another driver for this technology is that clean CO_2 may be as valuable as the LNG.

Issues to Consider for LNG Availability

The supply network for LNG motor fuel is not as mature as that for conventional fuels. There is the potential for interruption of supply for a variety of reasons. Hence, when implementing LNG vehicles in a fleet, special consideration will be needed concerning LNG supply and transportation. Issues to consider include:

- Guarantee of supply from the producer
- Supply during scheduled and unscheduled shutdown of the production plant
- Potential backup supply in case of scheduled or unscheduled loss of production
- Regional availability of transportation (tanker trucks) for fuel
- Transportation interruption – potential for labor strikes or roadway blockage such as blocked mountain passes during cold weather
- Added cost of backup supply and transportation in case of interruptions

Fuel Use and Delivery Strategy

Fleet LNG storage tanks are normally designed to hold fuel for 7 to 10 days without the need to vent gas and pressure. Fleet operators will need to decide how much buffer they should have on hand at any one time to cover shortage when fuel is not available due to supply or transportation problems. At the same time, frequent, unnecessary fuel deliveries to “top off” the storage tanks may add unnecessary cost. After an LNG fleet has been established and is operating reliably, effort should be given to optimizing fuel delivery schedule based upon fuel usage patterns and the acceptable strategies for fuel interruption.

Fuel Purchasing Strategy

Purchasing LNG fuel can be a complex process. It is important to understand the options available to your fleet and how your source of fuel will affect your operations. The fuel purchasing approach along with other startup concerns are discussed further in the subsection, **How Do We Get Started?**

LNG Distribution Company Profiles

There are basically two LNG suppliers for transportation in the U.S. – ALT-USA and Blue Fuels Group. These two companies are described below.

ALT-USA – ALT, short for Applied LNG Technologies, is a complete LNG company, capable of providing the necessary fuel stations and storage tanks, as well as the fuel itself. Based out of Amarillo, Texas, ALT is capable of providing many LNG services and products with stations located throughout the Southwest. Their most recent enterprise has been the development and implementation of four small-scale liquefier plants in Kern County, California; Amarillo, Texas; San Diego, California; and Simi Valley, California. LNG is transported for ALT by Jack B. Kelley, Inc., both companies are owned by the same parent company.

Web site:
www.altlngusa.com

Blue Fuels Group (formerly Lone Star Energy Company) – Blue Fuels is a subsidiary of Blue Energy and Technology, LLC. Blue Fuels Group provides full service for designing and building fuel stations and providing contracted LNG tanker-truck fuel deliveries. Blue Fuels Group is located in the Dallas, Texas area and supplies LNG fuel for several fleets in the area.

Web site:
www.bluefuels.com

LNG Fuel Station Design and Construction Suppliers

There are several companies that supply services for setting up fueling stations, fuel supply, and construction for fueling station installations. As mentioned above, Blue Fuels Group provides both fuel and fuel station services.

NexGen Fueling (Chart Industries) – NexGen Fueling provides on-board vehicle LNG fueling systems (nearly the only supplier of LNG vehicle fueling systems) and full-service design and implementation of fueling stations and support equipment. NexGen Fueling also provides project management of new LNG installations and after market support of existing LNG vehicle and fueling station equipment.

Web site:
www.nexgenfueling.com

ENRG (formerly eFuels and Pickens Fuel Corp) – ENRG designs, installs, and services natural gas fuel stations throughout California, Arizona, Ontario and British Columbia. They offer full service LNG fueling options including owning, installing, and providing LNG fueling.

Web site:
www.enrgfuel.com

CH-IV – CH-IV provides engineering consulting to support owners and operators of LNG facilities. CH-IV is prepared to provide support for nearly all aspects of the LNG procurement and operations stages. CH-IV is based in Maryland, but has contributed to LNG operations at many locations both within the United States and abroad.

Web site:
www.ch-iv.com

CryoFuel Systems – CryoFuel Systems develops the equipment needed for liquefaction and dispensing of natural gas. They are working on developing both small-scale liquefaction systems as well as landfill gas purification equipment. In addition, CryoFuel Systems can design and build fueling stations or other necessary LNG equipment. Based in Monroe, Washington, CryoFuel Systems can provide many technological LNG solutions.

Web site:
www.cryofuelsystems.com

General Physics – Based in Columbia, MD but with offices across the United States and around the world, General Physics has the capabilities to design, construct, install, and maintain LNG and CNG fueling facilities. Their latest project, an LNG-LCNG fueling station for Omnitrans in San Bernardino County, CA, has been designed to be capable of fueling 200 CNG buses nightly.

Web site:
www.gpworldwide.com

Northstar Industries – Northstar Industries provides manufacturing and construction of prepackaged, modular LNG facilities. Northstar is based out of Massachusetts, but has developed LNG projects throughout the east coast.

Web site:
www.northstarind.com

Liberty Fuels, Inc. – Liberty Fuels offers a skid mounted, small-scale liquefaction and LNG fuel dispensing system.

Web site:
www.libertyfuels.com

The best sources for more information of fuel and fuel station service providers is in the NGV Resource Guide (www.ngvc.org) and DOE's Alternative Fuel Data Center (www.afdc.doe.gov).

What Will This Cost Me?

The general path to cost-effective implementation of LNG vehicles into your fleet will require doing your homework, creating a network of resources and contacts, working with experts in LNG, and building your own expertise in LNG. The costs associated with using LNG vehicles will differ in many cases from the costs associated with conventional vehicles. The cost of the LNG will generally be lower than diesel on an energy equivalent gallon basis. However, this lower fuel cost may not translate into overall savings because natural gas engines generally have lower fuel efficiencies than diesel engines. The optimal situation for achieving reduced fuel cost with LNG is in high-mileage, high-speed applications. There may be cases where the price of LNG will be low and translate into significant cost savings.

Experience has shown that once maintenance personnel become familiar with maintaining LNG vehicles, the maintenance costs associated with LNG vehicles are typically only slightly higher than those costs associated with diesel vehicles. To overcome the additional costs associated with purchasing and operating LNG vehicles, fleet mangers may be able to obtain funding from federal, state, and local governmental agencies. In addition to funding, there may be tax breaks associated with the use of LNG that fleets can also take advantage of. The subsections **Why Alternative Fuels?** and **How Do We Get Started?** include directions on how to obtain funding as well as advice regarding the purchasing process.

Although using LNG may require additional economic burdens even with funding incentives and tax breaks, fleets should consider the value of using environmentally friendly vehicles. This environmental contribution can help improve the image of your organization in the eyes of your employees, your customers, and your surrounding community. This subsection will outline the costs that may be associated with implementing LNG vehicles. All of these costs should be carefully considered before committing to using LNG, but fleet managers should consider the benefits of LNG as well.

Fuel Costs

Many factors can affect the cost of purchasing LNG fuel. Fleets located near peak-shaving facilities may be able obtain LNG at a significantly lower price than other fleets. Peak-shaving facilities generate LNG for storage in order to meet the high demand for natural gas during the peak heating/winter months. Fleets, which are not located near these types of facilities, will need to pay additional costs to transport LNG from LNG producing facilities to their area, use small-scale liquefaction equipment to convert natural gas to LNG at their fueling facility, or use an outside/existing fueling facility. The source of LNG fuel that a fleet uses can have a major effect on the cost of their fuel. Another issue is the required fuel quality, specifically methane content or methane number will affect cost. There may also be fuel taxes associated with LNG, which vary from state to state. Fleet users should explore what LNG will cost in their area, because location is usually the major factor affecting the cost of LNG fuel.

The federal LNG fuel tax has been defined as $0.119 per LNG gallons for private fleets. Most state and municipal fleets including transit are exempt from this tax. The diesel federal fuel tax is $0.244 per diesel gallon and the same fleets are exempt from this federal excise tax. There is also a state excise tax for fuels in most states and this tax can be slightly different depending on the type of fleet. Many states and local jurisdictions also provide tax incentives for the use of alternative fuel use including LNG. An understanding of these taxes and credits can be gained from several sources including the following:

- Clean Cities: www.ccities.doe.gov
- NGV Resource Guide: www.ngvc.org
- Liquefied Natural Gas for Heavy-Duty Transportation, 2001: www.gastechnology.org
- Clean Fuels Report (periodical): www.energy-futures.com

Cost factors vary between natural gas vehicles and those using gasoline or diesel. On average, natural gas is cheaper than diesel, but LNG generally costs the same or slightly less than diesel on an equivalent energy basis. Your fleet's location can have a major effect on the cost of LNG fuel. LNG is available at production-sites at costs considerably lower than rack diesel prices. However, if LNG must be trucked for more than 500 miles, LNG prices may not be able to compete with the cost of diesel fuel. For fleets far from LNG production facilities, high volumes and efficient operations must be achieved for LNG costs to be competitive with diesel or gasoline. Unless the fleet's fueling site is relatively close to the LNG production facility, a minimum of 40 to 50 heavy-duty trucks or buses (using 2,000 to 3,000 gallons per day) would be required to compete cost-wise with diesel.

As stated earlier, because of the reduced fuel efficiency of LNG and the similar costs on an energy basis, fuel costs for LNG vehicles will usually end up slightly higher than the fuel costs for diesel vehicles. This gap narrows if vehicles are driven on high-mileage, high-speed duty cycle because efficiencies improve when vehicles are driven at higher speeds for spark-ignited natural gas engines.

Vehicle Costs

LNG vehicles will typically cost more than conventional vehicles because of the higher cost to integrate new technologies into the vehicles. Heavy-duty LNG vehicles generally have an incremental cost of $30,000 to $60,000 over conventional diesel vehicles. The incremental cost for natural gas engines can be as low as $5,000 or as high as $45,000, depending on the manufacturer and the performance of the engine. The other increased costs associated with LNG vehicles include fuel storage and delivery systems as well as LNG safety systems. Figure 2-30 shows an LNG refuse truck.

Figure 2-30. LNG Refuse Truck at Taormina Industries

Fueling Station Costs

There are different options when deciding how to fuel LNG vehicles and each option will correlate to different associated costs. Fleets should understand what options are available to them, what level of performance is expected from each option, and what initial and continuing costs are associated with each option.

One option that may be available is use of an outside fueling station. This will mean using another fleet's fueling facility. Fleets should examine what options are available in their area. Using an outside fueling station will mean that the capital costs of the station are passed along through the price of the fuel. This may be a good option for smaller LNG fleets especially if the outside fueling station is located nearby. Fleets considering this option should find out what an outside fueling company intends to charge and if possible how the fuel price breaks down into capital and other costs. This should give the user an indication as to how the fuel price will fluctuate with the cost of natural gas. Also, a survey of LNG and CNG users found that a fleet that had on-site fueling was more likely to have a successful experience implementing natural gas vehicles[15].

If a fleet decides to build its own fueling station, which will be the only alternative in most areas, there are many factors that will affect the cost of the fueling facility. The biggest factors will be how much fuel your fleet will use and how much time is available for fueling. This will affect how much fuel storage is needed at your facility and what type of dispensing system will be

[15] Eudy, L., Natural Gas in Transit Fleets: A Review of the Transit Experience, NREL/TP-540-31479, 2002.

required. Fleets should be careful to make sure their fueling facility has enough capability to keep their LNG vehicles running as effectively as their conventional vehicles. Sizing should take into account not only the needs of the immediate future but also what the fleet will require further down the line if it expects to purchase additional LNG vehicles. Fleets should consider incorporating the ability to defuel the vehicle into a fueling station. If the fueling station has this ability, then fuel that must be removed from the vehicles for maintenance purposes can be reclaimed by the fueling station. Otherwise the fuel will need to be vented to the atmosphere.

Figure 2-31. LNG Fueling Station at DART in Dallas, Texas

Facility Modifications

Fleets will most likely need to make modifications to their existing maintenance facilities in order to provide a safe environment to perform maintenance on LNG vehicles. Such modifications could include addition of methane detection systems, roof vents and fans to prevent accumulation of flammable gases, as well as any special tools or equipment needed to perform LNG vehicle maintenance. These costs may be controlled by designating certain areas of the maintenance facility for working on LNG vehicles. If this is done only these areas will need to be converted. When considering what modifications are needed for a given fleet, a team of reputable and experienced architects and engineers should be consulted to assess what modifications are necessary. Note that the older the facilities are, the more cost that will most likely be required to upgrade the ventilation system.

Fleet Cost Summaries

In order to better understand the potential costs of LNG vehicle operations, the costs of several evaluation fleets are shown below. Further information on these fleets is available in the references listed after the summaries.

Waste Management Cost Summary				
Vehicle	**Fuel Cost/ Mile ($)**	**Engine Oil Cost/ Mile ($)**	**Maintenance Cost/ Mile ($)**	**Total Cost/ Mile ($)**
Waste Management Diesel Refuse Hauler Average	0.410	0.001	0.519	**0.930**
Waste Management LNG Refuse Hauler Average	0.826	0.003	0.845	**1.674**
	Fuel Cost/ Engine Hour ($)	**Engine Oil Cost/ Engine Hour ($)**	**Maintenance Cost/ Engine Hour ($)**	**Total Cost/ Engine Hour ($)**
Waste Management Diesel Refuse Hauler Average	4.699	0.008	5.954	**10.66**
Waste Management LNG Refuse Hauler Average	7.233	0.024	7.319	**14.576**
The LNG trucks had an incremental cost of about $40,000.				
The fueling station cost roughly $500,000 to build initially. LCNG capabilities were added later. The cost to build the combined configuration with LNG and CNG capabilities would cost between $700,000 and $750,000. The station serves seven LNG refuse trucks.				

DART Cost Summary				
Vehicle	**Fuel Cost/ Mile ($)**	**Engine Oil Cost/ Mile ($)**	**Maintenance Cost/ Mile ($)**	**Total Cost/ Mile ($)**
DART MY1998 Diesel Transit Bus Average	0.238	0.001	0.534	**0.773**
DART MY1998 LNG Transit Bus Average	0.314	0.002	0.484	**0.799**
DART MY1999 LNG Transit Bus Average	0.314	0.001	0.398	**0.713**
The LNG buses had an incremental cost of about $39,400 with LNG busses costing about $330,000 compared to $290,000 for comparable diesel buses				
Maintenance facilities modifications cost about $7.5 million for design, construction, and start-up. $3.6 million of these costs were attributed to the fueling stations. These fueling facilities service roughly 140 buses, but were designed to be capable of servicing at least 70 more buses.				

Raley's Cost Summary			
Vehicle	**Fuel Cost/ Mile ($)**	**Maintenance Cost/ Mile ($)**	**Total Cost/ Mile ($)**
Raley's MY1996 Diesel Truck Average	0.144	0.048	**0.348**
Raley's MY1997 LNG Truck Average	0.252	0.096	**0.348**
The LNG trucks had an incremental cost of about $35,000.			
The 13,000 gallon LNG fueling station cost about $350,000			

Resources:

Waste Management's LNG Truck Fleet Final Results www.afdc.doe.gov/pdfs/WasteLNGfinal.pdf

Waste Management's LNG Truck Fleet Final Data Report [Free copies available by calling the National Alternative Fuels Hotline at (800) 423-1363]

DART's LNG Bus Fleet Final Results www.nrel.gov/docs/fy01osti/28739.pdf

DART's LNG Bus Fleet Final Data Report [Free copies available by calling the National Alternative Fuels Hotline at (800) 423-1363]

Raley's LNG Truck Fleet Final Results www.afdc.doe.gov/pdfs/Raleys.pdf

Raley's LNG Truck Fleet, Final Data Report [Free copies available by calling the National Alternative Fuels Hotline at (800) 423-1363]

Eudy, L., Natural Gas in Transit Fleets: A Review of the Transit Experience, NREL/TP-540-31479, 2002.

AD Little, Liquefied Natural Gas for Heavy-Duty Transportation, GTI, 2002.

Training

One of the most important aspects of successfully incorporating LNG vehicles into a fleet is learning about the technology. This is not only important for the decision makers within the fleet but also for anyone who comes in contact with the vehicle. The OEMs who supply the vehicles or LNG equipment should be able to direct fleets towards appropriate training courses if they do not offer courses themselves.

Typically, a fleet will send a few members of their personnel to formal training so that they will be able to train other personnel. All members of a fleet's staff should at least receive minimal training so that they are generally aware of the hazards associated with LNG. Personnel should take the time to develop documentation of safety procedures and plans for emergency situations. Then it is important to communicate these procedures to the appropriate personnel. Those personnel responsible for the operations and maintenance of the LNG vehicles will require additional training to understand how the vehicles work and how they should be inspected and maintained. Eventually, LNG training should be incorporated into the standard training given to new hires and the on-going training for existing personnel. The costs associated with this training may encourage fleets to try to get by with as little training as they can, but spending on training up front can have a big payoff later by preventing costly incidents and vehicle downtime.

In addition to formal training, LNG fleets should create a habit of collecting general LNG materials. The fleet should try to learn as much as it can about this new technology. Other ways of gathering information include communicating with other fleets that are using LNG technology. This can be done by participating in working groups and attending conferences. Fleets may find that the experiences of others are the best way to learn about their vehicles, and it can often be done at minimal cost.

Personnel

There will probably be a need for additional personnel costs especially in the early stages of LNG operation. As staff become familiar with the vehicles, they may need more time to perform routine maintenance operations such as filter changes as well as any larger repairs which may be needed. There may also be a need to acquire engineering support to perform troubleshooting and benchmarking.

Extra Costs at Start-Up

As LNG vehicle operations begin there will be several costs, which will occur up-front. In addition to the cost to purchase the vehicles, additional training will be needed as soon as the vehicles arrive if not sooner. Troubleshooting of maintenance issues will take more time until your staff become familiar with the vehicles. The vehicle and component manufacturers may have to be consulted regularly in the early stages of operation to support setting-up and troubleshooting the vehicles.

There also may be marketing costs associated with an LNG venture. Marketing outside of the fleet is important to raise public support for the project. This may include the cost of painting the vehicles so they are easily identifiable as alternative fueled vehicles, or setting up a public demonstration of the vehicles. It is also important to market the project within the fleet. The introduction of LNG vehicles will require support from staff at all levels of an organization. An in-house marketing campaign should be considered to motivate everyone to make the changes in their routines, which are necessary in order for LNG vehicles to be successful. Proper marketing of your LNG program is crucial to tapping into the non-financial benefits associated with LNG vehicles that were discussed earlier.

Long-Term Operational Cost Increases

Besides the initial startup costs, there are many additional operational costs, which will be incurred over the long run. The additional equipment added to support LNG vehicles will bring additional maintenance costs. A fueling station, gas detection systems, and any other added equipment will need additional maintenance. These maintenance costs may be higher than those associated with conventional equipment. There may also be a need for more maintenance labor to deal with more sophisticated vehicles and systems. More labor may be needed to perform the inspections that are required for LNG vehicles. Fleets may also want to document more information regarding vehicle performance for benchmarking and troubleshooting, as well as record any vehicle complications and remedies. Documenting the performance of the vehicles as well as maintenance records will be useful when comparing the LNG vehicles to other vehicles and optimization of future operation and costs. This information will also be important to organizations supporting an LNG program.

Truly determining the costs of using LNG will require taking a close look at the options available in your area and the necessary costs that will impact your individual fleet. The following suggested tasks, organized by the aspects of operation that they pertain to, will help you to understand what your costs will be and help you to make final decisions.

Vehicles

- Identify representatives available from engine, vehicle, and fuel manufacturers who can help with initial planning, problem solving and trouble-shooting. This can save you hours of staff time during the planning, start-up phase, and full-scale operations.
- Estimate the power needs and range of your specific vehicles.
- Decide how to stage the purchase, replacement, and delivery of the new vehicles.
- Clearly define the operational differences related to the new fuel (e.g., how operations will change with regard to training drivers, fuelers, and maintenance personnel, as well as range, fuel availability, and power).
- Calculate the usage and fuel consumption of the vehicles (e.g., amount of fuel used per mile) based on fleet and manufacturer estimates.

Facilities – Fueling, Maintenance, and Others

- Examine the effects of using LNG on your current site layout.
- Determine the cost to modify or construct vehicle maintenance and storage facilities.
- Determine the size of the fueling station(s) and type of fuel storage facility.
- Solicit fuel cost estimates and select a preferred vendor.
- Determine the staff time and cost of regulatory preparation steps, obtaining permits, consulting with safety and fire officials, and addressing building codes.

Operations and Training

- Examine the cost of training (and retraining) personnel involved in operating, maintaining, fueling, or supervising the new fleet.
- Develop methods to track the fuel, performance, maintenance costs, and personnel issues for comparison with vehicles using gasoline or diesel fuel.
- Determine potential roadblocks or problems and prepare workarounds in advance.
- Ask representatives of companies that recently installed an LNG facility what lessons they learned during the process of switching to and using LNG.

The cost of operating an LNG fleet will vary depending on location, preparedness, and size of operation. By gathering enough information, however, fleets can begin to grasp what costs will be associated with using LNG vehicles and making them successful. Further information regarding the costs associated with LNG operation is available in *Liquefied Natural Gas for Heavy-Duty Transportation* from GTI at www.gastechnology.org.

Where Can I Find More Answers?

There are several sources available to provide answers to many of your questions. These sources include companies that supply LNG, consultants who provide advice to potential users of LNG, and companies with fleets powered by LNG. Additional information and lists of LNG suppliers, consultants, and fleets using LNG in routine operations are available in this guide.

Several federal and state government Web sites, and the U.S. Department of Energy's Alternative Fuel Data Center (AFDC) Web site provide access to alternative fuel reports, brochures, analyses of LNG demonstrations, and documents and publications that may be useful. Here are web site addresses that may be useful for fleet managers who have added LNG vehicles to their fleets recently:

- Alternative Fuels Hotline: 1-800-423-1DOE
- Alternative Fuels Data Center: www.afdc.doe.gov
- DOE's Office of Transportation Technologies: www.ott.doe.gov
- DOE's Office of Transportation Technologies, Heavy Vehicle Projects: www.ctts.nrel.gov/heavy_vehicle or www.ctts.nrel.gov/ngngv
- Clean Cities Program: www.ccities.doe.gov
- California Energy Commission—About Natural Gas Vehicles: www.energy.ca.gov/afvs
- Calstart: www.calstart.org/fleets
- National Association of State Energy Officials: www.naseo.org/energy_sectors/stateenergy (click on alt fuels)
- Natural Gas Vehicle Coalition: www.ngvc.org (especially the NGV Resource Guide)
- Cummins Westport: www.cumminswestport.com

Fleet Experiences

The experiences of fleets that have already performed alternative fuel implementations will be especially helpful. Reports on experiences using LNG and other alternative fuels are listed below.

LNG Start-Up Experiences:

Raley's LNG Truck Fleet Start-Up Experience: www.afdc.doe.gov/pdfs/raley-lng.pdf

Waste Management's LNG Truck Fleet Start-Up Experience: www.nrel.gov/docs/fy99osti/26617.pdf

DART's LNG Bus Fleet Start-Up Experience: www.nrel.gov/docs/fy00osti/28124.pdf

Other Alternative Fuel Vehicle Start-Up Experiences:

UPS CNG Truck Fleet Start-Up Experience: www.afdc.doe.gov/pdfs/ups_cng.pdf

Dual-Fuel Truck Fleet Start-Up Experience: www.afdc.doe.gov/pdfs/pimagro.pdf

Ralphs Grocery EC-Diesel™ Truck Fleet Start-Up Experience: www.afdc.doe.gov/pdfs/Ralphs_ECD.pdf

Denver SuperShuttle CNG Fleet Evaluation: www.ott.doe.gov/pdfs/supershuttle.pdf

Class 8 Trucks Operating on Ultra-low Sulfur Diesel with Particulate Filter Systems: A Fleet Start-up Experience SAE paper #2000-01-2821, October 2000 [Available for purchase at www.sae.org/]

LNG Fleet Final Results:

Raley's LNG Truck Fleet Final Results: www.afdc.doe.gov/pdfs/Raleys.pdf

Raley's LNG Truck Fleet, Final Data Report [Free copies available by calling the National Alternative Fuels Hotline at (800) 423-1363]

Waste Management's LNG Truck Fleet Final Results: www.afdc.doe.gov/pdfs/WasteLNGfinal.pdf

Waste Management's LNG Truck Fleet Final Data Report [Free copies available by calling the National Alternative Fuels Hotline at (800) 423-1363]

DART's LNG Bus Fleet Final Results: www.nrel.gov/docs/fy01osti/28739.pdf

DART's LNG Bus Fleet Final Data Report [Free copies available by calling the National Alternative Fuels Hotline at (800) 423-1363]

Heavy-Duty Truck Demonstration with a 400-Hp DDC Series 60G LNG Engine, and Support for the Downtown Los Angeles LNG Station, ARCADIS (AD Little). [The report is available from Arthur D. Little Acurex Energy, (714) 278-0992].

LNG Heavy-Duty Truck Demonstration Program, June 2000. [The report is available from Arthur D. Little Acurex Energy, (714) 278-0992].

Using LNG as a Fuel in Heavy-Duty Tractors: www.nrel.gov/docs/fy99osti/24146.pdf

Development of LNG-Powered Heavy-Duty Trucks in Commercial Hauling: www.nrel.gov/docs/fy99osti/25154.pdf

LNG: A Report from the Field, Fleet Equipment Magazine, August 1997: www.truklink.com/articles/te/article0066.html

Other Alternative Fuel Vehicle Final Results:

Alternative Fuel Transit Buses: Final Results from the National Renewable Energy Laboratory (NREL) Vehicle Evaluation Program: www.afdc.doe.gov/pdfs/transbus.pdf

UPS CNG Truck Fleet Final Data Report DOE/NREL Truck Evaluation Project [Free copies available by calling the National Alternative Fuels Hotline at (800) 423-1363]

Ralphs Grocery EC-Diesel™ Truck Fleet Final Data Report [Free copies available by calling the National Alternative Fuels Hotline at (800) 423-1363]

SuperShuttle CNG Fleet Evaluation – Final Report: www.ott.doe.gov/otu/field_ops/pdfs/supershuttle_final.pdf

Development of an Ultra-Safe, Ultra-Low Emissions Natural Gas-Fueled School Bus: Final Report [Free copies available by calling the National Alternative Fuels Hotline at (800) 423-1363]

Natural Gas in Transit Fleets: A Review of the Transit Experience: www.ott.doe.gov/otu/field_ops/cng_survey.html

Training Resources

The following web sites are operated by organizations that provide training for alternative fuel service and maintenance personnel. In addition to the organizations that operate the following web sites, the vendors and manufacturers of LNG equipment also will be able to provide training.

Natural Gas Vehicle Institute: www.ngvi.com

National Automotive Technicians Education Foundation: www.natef.org

National Institute for Automotive Service Excellence: www.asecert.org

The National Alternative Fuels Training Consortium: naftp.nrcce.wvu.edu

SECTION 3

THE APPENDIX

References

LNG-Related Periodicals

LNG-Related Internet Sites

LNG Fleets

What's In This Section?

This section lists sources of additional information on LNG vehicle operations and implementation.

	CONTENT CATEGORIES																ORDERING INFORMATION		
	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
Reference	General (Backgroud, History, Cost, Production, etc.)	Chemical Properties	Supply/Availability	General (Issues, Start-Up Problems, Incentives)	Vehicle & Engine Availability	Vehicle Performance (Range, Emissions, Operating Costs, etc.)	General (Issues, Start-Up Problems)	Fueling Station (Design, Process, Cost, Other Issues)	Maintenance Facilities (Requirements, etc.)	Other Facilities (Storage Facilities, etc.)	General (Issues, Start-Up Problems)	Training (Necessary Personal, Training Basics, Timing of Training)	Implementation	General (Risk Assessment)	Procedures	Standards	Available Electronically	Cost (Member/Non-Member Price)	Ordering Information
"A Model Emergency Response Plan", Professional Safety, Brown, B.A., American Society of Safety Engineers, January 1995												✓			✓				
A Current Look at the Natural Gas Fueling Infrastructure in the United States, Thomason, L.B., II, Society of Automotive Engineers. Inc., Warrendale, PA, 952770, 1995			✓				✓			✓								$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323
A Life Cycle Comparison of Alternative Transportation Fuels, Joshi, S., Lave, L., Maclean, H., Lankey, R., Society of Automotive Engineers Inc., Warrendale, PA, SAE-2000-01-1516, April 2000	✓	✓															✓	$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Alternative Fuel Truck Evaluation Project- Design and Preliminary Results, Chandler, K. L., Norton, P., Clark, N., Society of Automotive Engineers. Inc., Warrendale, PA, 981392, May 4-6, 1998				✓		✓											✓	$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Alternative Fuel Vehicles: Environmental and Economic Effects of Infrastructural Requirements, Horvath, A., Society of Automotive Engineers Inc., Warrendale, PA, SAE-2000-01-1482, April 2000							✓					✓		✓	✓		✓	$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Alternative Fuel: A Decision To Live With the OCTA Experience, Pierce, A., American Public Transportation Association, Proceedings of the 1998 Bus Operations, Technology, and Management Conference, 1998				✓			✓				✓								
Alternative Fuel: Transit Buses, DART's LNG Bus Fleet Final Data Report, Battelle, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, June 2000				✓		✓					✓						✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov

Reference	LNG: FUEL – General (Backgroud, History, Cost, Production, etc.)	LNG: FUEL – Chemical Properties	LNG: FUEL – Supply/Availability	VEHICLES – General (Issues, Start-Up Problems, Incentives)	VEHICLES – Vehicle & Engine Availability	VEHICLES – Vehicle Performance (Range, Emissions, Operating Costs, etc.)	INFRASTRUCTURE – General (Issues, Start-Up Problems)	INFRASTRUCTURE – Fueling Station (Design, Process, Cost, Other Issues)	INFRASTRUCTURE – Maintenance Facilities (Requirements, etc.)	INFRASTRUCTURE – Other Facilities (Storage Facilities, etc.)	SUPPORT – General (Issues, Start-Up Problems)	SUPPORT – Training (Necessary Personal, Training Basics, Timing of Training)	SUPPORT – Implementation	SAFETY – General (Risk Assessment)	SAFETY – Procedures	SAFETY – Standards	Available Electronically	Cost (Member/Non-Member Price)	Ordering Information
Alternative Fuels for Future Engines , Society of Automotive Engineers Inc., Warrendale, PA, SP-1468, August 1999				✓				✓									✓	$31.20/ $39.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Alternative Fuels , Society of Automotive Engineers Inc., Warrendale, PA, SP-1557, August 2000	✓						✓	✓									✓	$39.20/ $49.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Alternative Fuels: Alcohols, Hydrogen, Natural Gas, and Propane , Society of Automotive Engineers Inc., Warrendale, PA, SP-982, August 1993				✓		✓													Call SAE Customer Service @ (877) 606-7323
Alternatives to Traditional Transportation Fuels 1995 , Office of Coal, Nuclear, Electric and Alternate Fuels, U.S. Department of Energy, Energy Information Administration, U.S. Department of Energy, Washington, DC, DOE/EIA-0585(95), December 1996				✓	✓												✓	FREE	www.eia.doe.gov
Best Available Practices for LNG Fueling of Fleet Vehicles, Midgett, D.E., II, Gas Research Institute, Chicago, IL, GRI-96/0180, February 1996							✓	✓			✓	✓					✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org
Case Studies of Cost-Effective Natural Gas Fuel Stations , American Gas Association, Gas Research Institute, Chicago, IL, 1995								✓									✓	FREE	Call GTI @ (630) 406-5994 or www.gastechnology.org
Case Study: Sun Metro-6.2 Million Miles on Natural Gas, U.S. Department of Energy, Washington, DC, May 1997				✓		✓						✓					✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov

Reference	CONTENT CATEGORIES																ORDERING INFORMATION		
	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
Reference	General (Backgroud, History, Cost, Production, etc.)	Chemical Properties	Supply/Availability	General (Issues, Start-Up Problems, Incentives)	Vehicle & Engine Availability	Vehicle Performance (Range, Emissions, Operating Costs, etc.)	General (Issues, Start-Up Problems)	Fueling Station (Design, Process, Cost, Other Issues)	Maintenance Facilities (Requirements, etc.)	Other Facilities (Storage Facilities, etc.)	General (Issues, Start-Up Problems)	Training (Necessary Personal, Training Basics, Timing of Training)	Implementation	General (Risk Assessment)	Procedures	Standards	Available Electronically	Cost (Member/Non-Member Price)	Ordering Information
Clean Air Program: Design Guidelines for Bus Transit Systems Using Liquefied Natural Gas (LNG) as an Alternative Fuel, Raj, P.K., Hathaway, W.T., Kangas, R., U.S. Department of Transportation Federal Transit Administration, Washington, DC, DOT-FTA-MA-26-7021-97, March 1997						✓		✓	✓	✓					✓		✓	$29.50	Call the National Technical Information Service/NTIS @ (703) 487-4650 or www.ntis.gov
Clean Air Program: Liquefied Natural Gas Safety in Transit Operations, Friedman, D.M., Malcosky, N.D., U.S. Department of Transportation Federal Transit Administration, Washington, DC, DOT-FTA-MA-90-7007-95-3, March 1996								✓	✓	✓		✓		✓	✓		✓	$45.00	Call the National Technical Information Service/NTIS @ (703)-487-4650 or www.ntis.gov
Clean Air Program: Properties of Alternative Fuels, Murphy, M.J., U.S. Department of Transportation Federal Transit Administration, Washington, DC, FTA-OH-06-0060-94-1, March 1994		✓															✓		Call the National Technical Information Service/NTIS @ (703)-487-4650 or www.ntis.gov
Clean Air Program: Summary of Assessment of the Safety, Health, Environmental and System Risks of Alternative Fuel, Murphy, M.J., Ketola, H.N., Raj, P.K., U.S. Department of Transportation Federal Transit Administration, Washington, DC, DOT-FTA-MA-90-7007-95-1, August 1995														✓			✓		Call the National Technical Information Service/NTIS @ (703)-487-4650 or www.ntis.gov
Contribution Feedstock and Fuel Transportation to Total Fuel-Cycle Energy Use and Emissions, He, D., Wang, M., Center for Transportation Research, Society of Automotive Engineers Inc., Warrendale, PA, SAE-2000-01-2976, October 2000			✓														✓	$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org

Reference	CONTENT CATEGORIES																ORDERING INFORMATION		
	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
	General (Backgroud, History, Cost, Production, etc.)	Chemical Properties	Supply/Availability	General (Issues, Start-Up Problems, Incentives)	Vehicle & Engine Availability	Vehicle Performance (Range, Emissions, Operating Costs, etc.)	General (Issues, Start-Up Problems)	Fueling Station (Design, Process, Cost, Other Issues)	Maintenance Facilities (Requirements, etc.)	Other Facilities (Storage Facilities, etc.)	General (Issues, Start-Up Problems)	Training (Necessary Personal, Training Basics, Timing of Training)	Implementation	General (Risk Assessment)	Procedures	Standards	Available Electronically	Cost (Member/Non-Member Price)	Ordering Information
Costs and Emission Reductions for Alternatively-Fueled Fleet Vehicles , Baker, R., Society of Automotive Engineers. Inc., Warrendale, PA, 952774, 1995				✓			✓	✓										$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323
DART'S LNG Bus Fleet: Final Results, Battelle, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, BR-540-28739, October 2000				✓		✓					✓						✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
DART's LNG Program Status, Spencer, D.E., Watkins, R., Presentation, American Public Transportation Association, Washington, DC, February 9, 2001				✓			✓				✓								
DATA BOOK for Cryogenic Gases and Equipment , Chart-MVE, Burnsville, MN, 1997		✓																	
Developments in Non-Traditional Uses of LNG, CH IV Corp., Millersville, MD, September 2000	✓			✓			✓										✓	FREE	www.ch-iv.com
Dual-Fuel Truck Fleet: Start-Up Experience, Battelle, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, BR-540-25118, September 1998				✓		✓	✓				✓						✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Effect of Gas Composition on Octane Number of Natural Gas Fuels, Kubesh, J., King, S.R., Liss, W.E., Society of Automotive Engineers. Inc., Warrendale, PA, SAE-922359, October 1992		✓				✓											✓		Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Effects of Alternative Fuel on the U.S. Trucking Industry, Ritchey, B., Shepard, W., Murphy, W., Russell, D., Francis, J., Turanski, A., Hoess, J., Schmelz, R., ATA Foundation, Inc., Trucking Research Institute, Alexandria, VA, November 1990	✓					✓								✓					Out of Print

Reference	CONTENT CATEGORIES																ORDERING INFORMATION		
	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
Reference	General (Backgroud, History, Cost, Production, etc.)	Chemical Properties	Supply/Availability	General (Issues, Start-Up Problems, Incentives)	Vehicle & Engine Availability	Vehicle Performance (Range, Emissions, Operating Costs, etc.)	General (Issues, Start-Up Problems)	Fueling Station (Design, Process, Cost, Other Issues)	Maintenance Facilities (Requirements, etc.)	Other Facilities (Storage Facilities, etc.)	General (Issues, Start-Up Problems)	Training (Necessary Personal, Training Basics, Timing of Training)	Implementation	General (Risk Assessment)	Procedures	Standards	Available Electronically	Cost (Member/Non-Member Price)	Ordering Information
Effects of Gas Composition on Engine Performance and Emissions, Ryan, T.W., Callahan, T.J., Gas Research Institute, Chicago, IL, GRI-91/0054, December 1991		✓				✓													Call GTI @ (630) 406-5994 or www.gastechnology.org
Energy Policy Act of 1992: Limited Progress in Acquiring Alternative Fuel Vehicles and Reaching Fuel Goals , U.S. General Accounting Office, Washington, DC, GAO/RCED-00-59, February 2000				✓													✓	FREE	Call General Accounting Office @ (202) 512-6000 or www.gao.gov
Final Results from the National Renewable Energy Laboratory Vehicle Evaluation Program, Battelle, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, TP-425-20513, October 1996				✓		✓	✓	✓	✓		✓		✓				✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Fischer-Tropsch Fuels for Southern California: Emissions Reduction Potential, Technology Options, and Market Outlook, Murphy, M.J., South Coast Air Quality Management District, California, September 1999		✓																	
From Research to Reality: Alternative Fuels in Commercial Trucking , American Trucking Association Foundation, Alexandria, VA, June 1997				✓			✓												
Greenhouse Gas Emissions: Transportation Sector , Topical Report, Darrow, K.G., Jr., Gas Research Institute, Chicago, IL, GRI-92/0182, June 1992						✓											✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org

	CONTENT CATEGORIES																ORDERING INFORMATION		
	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
Reference	General (Backgroud, History, Cost, Production, etc.)	Chemical Properties	Supply/Availability	General (Issues, Start-Up Problems, Incentives)	Vehicle & Engine Availability	Vehicle Performance (Range, Emissions, Operating Costs, etc.)	General (Issues, Start-Up Problems)	Fueling Station (Design, Process, Cost, Other Issues)	Maintenance Facilities (Requirements, etc.)	Other Facilities (Storage Facilities, etc.)	General (Issues, Start-Up Problems)	Training (Necessary Personal, Training Basics, Timing of Training)	Implementation	General (Risk Assessment)	Procedures	Standards	Available Electronically	Cost (Member/Non-Member Price)	Ordering Information
Heavy Vehicle and Engine Resource Guide , U.S. Department of Energy, Office of Transportation Technologies, Washington, DC, NREL/TP-540-31274, December 2001					✓												✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Heavy-Duty Natural Gas Vehicles, Engines and Fuel Supply TOPTEC: LNG Supply, Quality, and Price, Prietto, A.J., Mesa Pacific LNG, Presentation, November 1996			✓		✓	✓													
Heavy-Duty Truck Demonstration with a 400-HP DDC Series 60G LNG Engine, and Support for the Downtown Los Angeles LNG Station , ARCADIS Geraghty & Miller, FR-99-104, 2000				✓		✓											✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Interim Results from Alternative Fuel Truck Evaluation Project, Chandler, K. L., Norton, P., Clark, N., Society of Automotive Engineers Inc., Warrendale, PA, 1999-01-1505, May 3-6, 1999				✓		✓											✓	$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Introduction to LNG for Personnel Safety , American Gas Association, Arlington, VA, X08614, July 1986	✓						✓				✓	✓					✓	$24.00/ $60.00	www.aga.org
Introduction to LNG Safety , CH IV Corp., Millersville, MD, 95214, October 2000												✓		✓	✓			$99	Order Form @ www.ch-iv.com
Introduction to LNG Vehicle Safety , Topical Report, Gas Research Institute, Chicago, IL, GRI-92/0645, September 1992	✓			✓								✓			✓			$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org
Investigations of Low-Cost LNG Vehicle Fuel Tank Concepts, Final Report, O'Brien, J.E., Siahpush, A., Gas Research Institute, Chicago, IL, GRI-98/0015, January 1998						✓											✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org

	CONTENT CATEGORIES																ORDERING INFORMATION		
	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
Reference	General (Backgroud, History, Cost, Production, etc.)	Chemical Properties	Supply/Availability	General (Issues, Start-Up Problems, Incentives)	Vehicle & Engine Availability	Vehicle Performance (Range, Emissions, Operating Costs, etc.)	General (Issues, Start-Up Problems)	Fueling Station (Design, Process, Cost, Other Issues)	Maintenance Facilities (Requirements, etc.)	Other Facilities (Storage Facilities, etc.)	General (Issues, Start-Up Problems)	Training (Necessary Personal, Training Basics, Timing of Training)	Implementation	General (Risk Assessment)	Procedures	Standards	Available Electronically	Cost (Member/Non-Member Price)	Ordering Information
Liquefied Natural Gas - Heavy Duty Truck Applications, Hanshaw, G., Pope, G., Society of Automotive Engineers. Inc., Warrendale, PA, 952740, 1995	✓	✓															✓	$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Liquefied Natural Gas for Heavy-Duty Transportation , Arthur D. Little, Inc., Gas Technology Institute, Des Plaines, Illinois, FR-01-101, March 2002	✓		✓	✓				✓											Call GTI @ (630) 406-5994 or www.gastechnology.org
Liquefied Natural Gas for Trucks and Buses, Wegrzyn, J.E., Litzke, W.L., Gurevich, M., Society of Automotive Engineers Inc., Warrendale, PA, SAE-2000-01-2210, June 2000				✓				✓									✓	$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Liquefied Natural Gas Fuel Supply, Yoder, S. J., Amoco Research and Development, Presentation			✓																
Liquefied Natural Gas Fuel Use - Basic Training Manual, Battelle, Pine & Associates, U.S. Dept. of Transportation and Federal Transit Administration,	✓	✓		✓			✓				✓	✓			✓				Out of Print
Liquefied Natural Gas, Lom, W.L., Esso Petroleum Co., Ltd., Abington, Berkshire, England, 1974	✓	✓	✓							✓									Out of Print
Liquefied Natural Gas: Alternative Fuel of Choice, MVE Inc., CD-ROM, Burnsville, MN, May 1999	✓	✓		✓			✓				✓								
LNG - A Paradox of Propulsion Potential, McKay, D.J., Society of Automotive Engineers Inc., Warrendale, PA, 952742, 1995	✓	✓		✓	✓	✓	✓	✓			✓							$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323

	CONTENT CATEGORIES																ORDERING INFORMATION		
	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
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LNG - CNG Lubricating Oil Delivery System, Czachorski, M., Blazek, C., Kina, R., Topical Report, Gas Research Institute, Chicago, IL, GRI-97/0387, November 1997								✓									✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gti.org
LNG Information Book: 1981 , American Gas Association, Arlington, VA, X00981, 1981	✓	✓															✓	$24.00/ $60.00	www.aga.org
LNG Preventive Maintenance Guide , American Gas Association, Arlington, VA, 1984							✓					✓			✓		✓	$24.00/ $60.00	www.aga.org
LNG Refuse Hauler Handles Heavy-Duty Service , Tech Profile, Gas Research Institute, Chicago, IL, GRI-97/0268, August 1997				✓													✓	FREE	Call GTI @ (630) 406-5994 or www.gastechnology.org
LNG Vehicle Markets and Infrastructure , Final Report, Nimocks, R., Gas Research Institute, Chicago, IL, GRI-95/0423, September 1995			✓	✓	✓		✓	✓		✓							✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org
LNG Vehicle Markets and Infrastructure , Final Report, Nimocks, R.M., Gerych, Z., Johnson, J., Powars, C., Gas Research Institute, Chicago, IL, GRI-98/0196, March 1998			✓	✓	✓		✓	✓		✓							✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org
LNG Vehicle Technology, Economics, and Safety Assessment, Final Report, Powars, C.A., Moyer, C.B., Lowell, D.D., Gas Research Institute, Chicago, IL, GRI-94/0051, February 1994						✓		✓						✓			✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org
LNG Weather Effects-Theoretical and Empirical , Topical Report, Acker, G.H., Moulton, D.S., Gas Research Institute, Chicago, IL, GRI-92/0464, December 1992		✓		✓													✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org
LNG: The Clear Choice , Zeus Development Corporation, Houston, TX, 1993	✓	✓				✓													

	CONTENT CATEGORIES																ORDERING INFORMATION		
	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
Reference	General (Backgroud, History, Cost, Production, etc.)	Chemical Properties	Supply/Availability	General (Issues, Start-Up Problems, Incentives)	Vehicle & Engine Availability	Vehicle Performance (Range, Emissions, Operating Costs, etc.)	General (Issues, Start-Up Problems)	Fueling Station (Design, Process, Cost, Other Issues)	Maintenance Facilities (Requirements, etc.)	Other Facilities (Storage Facilities, etc.)	General (Issues, Start-Up Problems)	Training (Necessary Personal, Training Basics, Timing of Training)	Implementation	General (Risk Assessment)	Procedures	Standards	Available Electronically	Cost (Member/Non-Member Price)	Ordering Information
Mass Transit: Use of Alternative Fuels in Transit Buses, U.S. General Accounting Office, Washington, DC, RCED-00-18, December 1999				✓		✓	✓					✓					✓	FREE	Call General Accounting Office @ (202) 512-6000 or www.gao.gov
Materials from OCTA LNG training course, Orange County Transportation Authority, Orange, CA				✓			✓				✓	✓							
Motor Vehicle Fuels: Properties and Specifications, Murphy, M.J., Battelle Memorial Institute, Columbus, OH, February 2000		✓																	
Natural Gas 1998: Issues and Trends, U.S. Department of Energy, Energy Information Administration, Washington, DC, DOE/EIA-0560(98), April 1999			✓														✓	FREE	Download @ www.eia.doe.gov
Natural Gas as a Fuel Option for Heavy Vehicles, Wegrzyn, J.E., Litzke, W.L., Gurevich, M., Society of Automotive Engineers. Inc., Warrendale, PA, SAE-1999-01-2248, April 1999	✓			✓				✓									✓	$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Natural Gas as a Stationary Engine and Vehicular Fuel, Liss, W.E., Thrasher, W.H., Society of Automotive Engineers. Inc., Warrendale, PA, 912364, 1991					✓	✓													Call SAE Customer Service @ (877) 606-7323 or www.sae.org
Natural Gas Buses: Separating Myth from Fact, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, NREL/FS-540-28377, May 2000	✓			✓		✓	✓										✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Natural Gas in Transit Fleets: A Review of the Transit Experience, Eudy, L., U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, NREL/TP-540-31479, February 2002				✓			✓				✓						✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov

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	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
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Natural Gas Vehicle Purchasing Guide , Natural Gas Vehicle Coalition, Washington, DC, 2002 Edition, 2002					✓												✓	FREE	Download @ www.ngvc.org
NFPA 57: Standard for Liquefied Natural Gas (LNG) Vehicular Fuel Systems , National Fire Protection Association, Quincy, MA, 1999 Edition, August 1999														✓		✓	✓	$24.00/ $26.75	Call NFPA @ 1 (800) 344-3555 or www.nfpa.org
NFPA 59A: Standard for the Production, Storage, and Handling of Liquefied Natural Gas (LNG) , National Fire Protection Association, Quincy, MA, 1996 Edition, February 1996														✓		✓	✓	$24.00/ $26.75	Call NFPA @ 1 (800) 344-3555 or www.nfpa.org
NGV Resource Guide: A Comprehensive Guide to the Natural Gas Vehicle Industry , RP Publishing, Denver, CO, Sixth Edition, May 1998	✓			✓	✓	✓	✓	✓	✓										Call RP Publishing @ (303) 863-0521
OCTA Garden Grove Base LNG Storage & Dispensing System: CalARP/RMP, Final Report, Winefield & Associates, Orange County Transportation Authority, Orange, CA, October 2000							✓	✓		✓									
Physical Properties of Natural Gases at Cryogenic Conditions, Gonzales, M.H., Subramaniam, T.K., Kao, R.L., Lee, A.L., Institute of Gas Technology, Chicago, IL, 1968	✓	✓																	Out of Print
Proceedings of CNG-LNG Safety Workshop , California Energy Commission, California Air Resources Board, Gas Research Institute, South Coast Air Quality Management District, November 1998												✓			✓				
Proceedings of Liquefied Natural Gas Vehicle Systems: Training School, Chart Applied Technologies, Burnsville, MN, April 3-4, 2001	✓	✓		✓							✓	✓			✓				

Reference	CONTENT CATEGORIES: LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY			ORDERING INFORMATION		
	General (Backgroud, History, Cost, Production, etc.)	Chemical Properties	Supply/Availability	General (Issues, Start-Up Problems, Incentives)	Vehicle & Engine Availability	Vehicle Performance (Range, Emissions, Operating Costs, etc.)	General (Issues, Start-Up Problems)	Fueling Station (Design, Process, Cost, Other Issues)	Maintenance Facilities (Requirements, etc.)	Other Facilities (Storage Facilities, etc.)	General (Issues, Start-Up Problems)	Training (Necessary Personal, Training Basics, Timing of Training)	Implementation	General (Risk Assessment)	Procedures	Standards	Available Electronically	Cost (Member/Non-Member Price)	Ordering Information
Producing High Quality LNG at NGL Plants (From the Proceedings of the LNG Powered Transportation Conference), Houshmand, M., Presentation, Williams Field Services, January 23-25, 2001	✓																		
Publicly Accessible, Simple, Safe LNG Dispensing Stations, Beale, J.P., Society of Automotive Engineers. Inc., Warrendale, PA, 972662, August 1997								✓						✓				$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323
Qualitative Risk Assessment for an LNG Refueling Station and Review of Relevant Safety Issues, Sui, N., Herring, J.S., Cadwallader, L., Reece, W., Byers, J., Idaho National Engineering Laboratory, Idaho National Engineering Laboratory, Idaho Falls, ID, INEEL/EXT-97-00827 rev. 2, February 1998								✓						✓			✓	FREE	www.inel.gov
Raley's LNG Truck Fleet: Final Results, Battelle, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, BR-540-27678, May 2000				✓		✓	✓	✓	✓		✓						✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Raley's LNG Truck Fleet: Start-Up Experience, Battelle, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, BR-540-23402, October 1997				✓			✓				✓						✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Recommended Practices for LNG Powered Heavy-Duty Trucks , Society of Automotive Engineers. Inc., Warrendale, PA, SAE-J2343, January 1997														✓	✓		✓	$47.20/ $59.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org

	CONTENT CATEGORIES																ORDERING INFORMATION		
	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
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Reference Guide for Integration of Natural Gas Vehicle Fuel Systems, Stephens, D.R., Herridge, J.T., Gifford, M.T., B97 GRI-02/0013, January 2002				✓		✓		✓	✓				✓						
Risk Management Plan Guideline for LNG Vehicle Fueling Stations, Topical Report, Atallah, S., Saxena, S.K., Gustafson, R.M., Gas Research Institute, Chicago, IL, GRI-98/0245, October 1998								✓						✓			✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org
Self-Serve LNG Vehicle Fueling Stations, CH IV Corp., Lawrence, MA, LNG04B, February 1997								✓									✓	FREE	www.ch-iv.com
Standards for Liquefied Natural Gas, Code of California Regulations, Title 13, Article 2, Section 935, Department of the California Highway Patrol, California, 1994																✓	✓	FREE	http://ccr.oal.ca.gov/
State Alternative Fuel Vehicle Incentives: A Decade and More of Lessons Learned, Brown, M.H., Breckenridge, L., U.S. Department of Energy, Washington, DC, February 2001				✓													✓	FREE	www.ncsl.org
State of Alternative Fuels Technologies, Society of Automotive Engineers. Inc., Warrendale, PA, SP-1458, May 1999				✓													✓	$39.20/ $49.00	Call SAE Customer Service @ (877) 606-7323 or www.sae.org
TCRP Report 38: Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations, ARCADIS Geraghty & Miller Inc., Transportation Research Board, U.S. Department of Transportation Federal Transit Administration, Washington, DC, 1998	✓												✓				✓	FREE	www.trb.org

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	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY					
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The Buyer's Guide to Natural Gas Vehicle Products & Services , RP Publishing, Denver, CO, 1998 Edition, January 1998					✓														Call RP Publishing @ (303) 863-0521
The Cleaner Choice: Natural Gas as a Substitute for Diesel, Final Report, Weaver, C.S., Gas Research Institute, Chicago, IL, GRI-99/0261, December 1999	✓			✓			✓										✓	FREE	Call GTI @ (630) 406-5994 or www.gastechnology.org
The Effects of LNG Weathering of Fuel Composition and Vehicle Management Techniques, Gibbs, J.L., Bechtold, R.L., Collison, C.E., III, Society of Automotive Engineers. Inc., Warrendale, PA, SAE-952607, November 1995	✓	✓		✓														$8.00/ $10.00	Call SAE Customer Service @ (877) 606-7323
The Road to Cost Effective LNG, Heister, T., CryoFuel Systems, Inc., Monroe, WA, September 2000	✓		✓																
Underground LNG Storage System Evaluation , Final Report, Outtrim, P.A., Lewis, J.P., Gas Research Institute, Chicago, IL, GRI-97/0070, December 1997								✓		✓							✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org
Using LNG as a Fuel in Heavy-Duty Tractors, Liquid Carbonic, Inc., Trucking Research Institute, U.S. Department of Energy, National Renewable Energy Laboratory, Washington, DC, NREL/SR-540-24146, July 1999	✓			✓		✓											✓	FREE	Call 1-800-423-1DOE
Variability of Natural Gas Composition in Select Major Metropolitan Areas of the United States, Final Report, Liss, W.E., Thrasher, W.H., Steinmetz, G.F., Chowdiah, P., Attari, A., Gas Research Institute, Chicago, IL, GRI-92/0123, March 1992		✓	✓														✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org

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	LNG: FUEL			VEHICLES			INFRASTRUCTURE				SUPPORT			SAFETY				
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Waste Management's LNG Truck Fleet Final Data Report, Battelle, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, August 2000				✓		✓	✓	✓		✓	✓						✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Waste Management's LNG Truck Fleet: Final Results, Battelle, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, BR-540-29073, January 2001				✓			✓	✓			✓						✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Waste Management's LNG Truck Fleet: Start-Up Experience, Battelle, U.S. Department of Energy, National Renewable Energy Laboratory, Golden, CO, BR-540-26617, August 1999				✓			✓				✓						✓	FREE	Call 1-800-423-1DOE or www.afdc.doe.gov
Weathering of LNG in On-Board Storage Tanks, Kountz, K.J., Final Report, Gas Research Institute, Chicago, IL, GRI-99/0185, April 1999		✓		✓			✓										✓	$35.00/ $60.00	Call GTI @ (630) 406-5994 or www.gastechnology.org

LNG-Related Periodicals

"Resource Guide for Heavy-Duty LNG Vehicles, Infrastructure, and Support Operations"

Magazine/Newsletter Title	Publisher	Periodicity	Cost
Alternative Fuel News	U.S. Department of Energy Office of Transportation Technologies	Varies	FREE
Alternative Fuel Price Report	Clean Cities	Varies	FREE
AltFuels Advisor	Alexander Communications Group, Inc.	Monthly	$347 per year
Clean Fuels and Electric Vehicles Report	Energy Futures, Inc.	Quarterly	$425 per year
Fleets & Fuel	August Pacific Press	24 issues per year	$397 per year
Fuel Sense	ENRG	Monthly	FREE
LNG Express	Zeus Development Corporation	Monthly	$497 per year
Natural Gas Fuel Magazine	RP Publishing	Six issues per year	FREE for qualified recipients
NGV Worldwide	International Association for Natural Gas Vehicles	Quarterly	$375 per year

LNG-Related Internet Sites

"Resource Guide for Heavy-Duty LNG Vehicles, Infrastructure, and Support Operations"

Name of Site/Organization	**Internet Address**
Alternative Fuel Vehicle Fleet Buyer's Guide	www.fleets.doe.gov
Alternative Fuels Data Center	www.afdc.doe.gov
American Gas Association	www.aga.com
American Public Transportation Association	www.apta.com
Applied LNG Technologies	www.altlngusa.com
Argonne National Laboratory, GREET	www.transportation.anl.gov/ttrdc/greet/
Blue Fuels Group	www.bluefuels.com
Brookhaven National Laboratory	www.bnl.gov
Bureau of Transportation Statistics	www.bts.gov
California Air Resources Board (CARB)	www.arb.ca.gov
CARB/Moyer Program	arbis.arb.ca.gov/msprog/moyer/moyer.htm
California Energy Commission	www.energy.ca.gov/afvs
Calstart	www.calstart.org/fleets
CH-IV Cryogenics	www.ch-iv.com/lng/lngfact.htm
Clean Cities Program	www.ccities.doe.gov
CryoFuel Systems	www.cryofuelsystems.com
Cummins Westport	www.cumminswestport.com
DOE's Office of Transportation Technologies	www.ott.doe.gov
Energy Information Administration	www.eia.doe.gov
ENRG	www.enrgfuel.com
Environmental Protection Agency (EPA)	www.epa.gov/otaq/
Federal Transit Administration	www.fta.dot.gov
GTI – Gas Technology Institute	www.gastechnology.org
General Accounting Office	www.gao.gov
General Physics	www.gpworldwide.com
INEEL – Idaho National Engineering and Environmental Laboratory	www.inel.gov
Intergovernmental Panel on Climate Change (IPCC)	www.ipcc.ch
Liberty Fuels	www.libertyfuels.com
National Alternative Fuels Training Consortium	naftp.nrcce.wvu.edu
National Association of State Energy Officials (click on alt fuels)	www.naseo.org/energy_sectors/stateenergy
National Automotive Technicians Education Foundation	www.natef.org
National Fire Protection Association	www.nfpa.org
National Institute for Automotive Service Excellence	www.asecert.org
NREL Center for Transportation Technologies	www.ctts.nrel.gov
Natural Gas Vehicle Coalition	www.ngvc.org
Natural Gas Vehicle Institute	www.ngvi.com
NexGen Fueling (Chart Industries)	www.nexgenfueling.com
Northstar Industries	www.northstarind.com
Remote Gas Strategies	www.remotegasstrategies.com
Society of Automotive Engineers	www.sae.org
Transportation Research Board	www.trb.gov
Zeus Development Corp./LNG Express	www.lngexpress.com/welcome.htm

LNG Fleets

"Resource Guide for Heavy-Duty LNG Vehicles, Infrastructure, and Support Operations"

Fleet	Number of LNG Vehicles	Vehicle Information	Operation	Fuel Station Information
Ace Hardware (Los Angeles, CA)	1 LNG tractor	Kenworth T800, Class 8 tractor, Cummins L10-300G engine	Line-Haul	Ace fuels at different stations around Southern California. Most of their fueling is at the Ontario FleetStar station.
Albertsons (Los Angeles, CA)	5 LNG tractors, 20 on order	Tractors, DDC S60G and CAT C-10 dual fuel	Line-Haul	Mostly at Taormina Waste Industries' LNG fueling station in Anaheim
Bakersfield, City of	LNG buses		Transit	QRS (6,000 gallon skid-mounted tank)
Browning Ferris Industries	10 LNG/Diesel (Dual Fuel)	Peterbilt 320 chassis, CAT C-10 dual fuel	Refuse	Temporary fueling arrangement
Burtec (Los Angeles, CA)	25 LNG/Diesel (Dual Fuel) - 14 collection trucks and 11 transfer trucks	CAT C-12 for transfer trucks; CAT C-10 for collection trucks; all in Peterbilt chassis	Refuse	QRS fueling station (6,000 gallon skid mounted); permanent station under construction (Northstar/General Physics)
City of Tempe (Tempe, AZ)	100 LNG buses	NABI buses with Cummins C8.3G engines	Transit	2-15,000 gallon storage tanks, one dispenser.
Dallas Area Rapid Transit (Dallas, TX)	1) 139 LNG Buses 2) 250 CNG non-revenue pool cars 3) 45 LNG Buses on order	1) 1998 NovaBUS RTS, Cummins L10-280G 3) 2002 NovaBUS RTS, DDC S50G	Transit	Fueling facilities consists of two 30,000 gallon storage tanks, three pumps rated 60 gallons per minute (gpm), and three LNG dispensers (Northwest). Two 20,000 gallon storage tanks, three pumps rated 60 gpm, and three LNG dispensers (South Oak Cliff).
El Paso Mass Transit Department (El Paso, TX)	35 LNG buses; 42 LNG paratransit; 2 LNG support vehicles	New Flyer full-size buses with a Detroit Diesel Series 50 natural gas engine 30 foot BlueBird Q buses	Transit	Three 20,000 gallon cryogenically insulated bulk LNG tanks. Estimated construction cost was 3 million dollars.
G I Rubbish (Waste Management) (Simi Valley, CA)	10-15 LNG trucks	Mack Trucks and engines	Refuse	QRS (6,000 gallon skid-mounted tank)
Gary Public Transportation Corporation (Gary, IN)	8 LNG Buses		Transit	15,000 gallon bulk storage
Greater Austin Transportation Company (Austin, TX)	17 LNG Shuttle Buses		Transit	MVE fueling station with 13,000 gallon storage tank.

LNG Fleets

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Fleet	Number of LNG Vehicles	Vehicle Information	Operation	Fuel Station Information
Harris Ranch (San Joaquin Valley, CA)	12 LNG/Diesel (Dual Fuel); 14 more on order	Freightliner Century class tractors truck, CAT C-12 dual-fuel	Line-Haul	A 16,000 gallon public-access refueling station
HEB Grocery (Houston, TX)	22 LNG/Diesel (Dual Fuel) tractors; 12 more on order	Sterling tractors with Caterpillar C12 engines	Line-Haul	LNG fueling station with 19,000 gallons LNG in two tanks (13,000 and 6,000 gal) and 2 dispensers.
Idaho National Engineering and Environmental Laboratory (Idaho Falls, ID)	8 LNG Coaches	MCI, converted DDC S60G	Over the Road Coach	LNG/LCNG Northstar station, 16,000 gal
Jack B. Kelley (San Manuel, AZ)	10 LNG	Kenworth T800, Class 8 tractor truck with a Cummins L10-300G engine	Line-Haul	Various fuel stations throughout the Western U.S.
LA Sanitation (Los Angeles, CA)	12 LNG/Diesel (Dual Fuel); 100 more on order	Peterbilt 320 chassis	Refuse	City is currently working to build two LNG/LCNG fueling stations, 2002/2003 timeframe; each station is planned with 60,000 gallons of LNG storage and 6 LNG dispensing nozzles.
LAX (Los Angeles, CA)	55 LNG shuttle buses	Gillig buses, Cummins engines	Transit	13,000 gallon LNG/LCNG fueling station
NorCal/Sanitary Fill (San Francisco, CA)	14 LNG trucks	Refuse trucks, Cummins Westport ISX-G	Refuse	NexGen Fueling station with 15,000 gallons storage
OmniTrans (San Bernardino, CA)	LCNG		Transit	OmniTrans is currently working with Northstar/General Physics to construct two 30,000 gallon LCNG fueling stations, completion in 2002.
Orange County Transportation Authority (Orange County, CA)	232 LNG buses	NABI buses; Detroit Diesel Series 50G	Transit	2 fueling stations, one at each operating depot (Garden Grove and Anaheim, CA).

LNG Fleets

"Resource Guide for Heavy-Duty LNG Vehicles, Infrastructure, and Support Operations"

Fleet	Number of LNG Vehicles	Vehicle Information	Operation	Fuel Station Information
Raley's (Sacramento, CA)	1) 8 LNG Class 8 tractors 2) 2 LNG yard tractors 3) 1 LNG Class 8 tractor	1) Kenworth T800, Class 8 tractor, Cummins L10-300G 2) Ottawa yard tractor, Cummins B5.9G 3) Class 8 tractor, Cummins Westport ISX-G	Line-Haul	Initially, a 5,000 gallon Quick Response System (QRS) temporary station was used. In November 1998, a permanent, 13,000 gallon refueling station was completed at an estimated cost of $350,000
Sacramento County	15 LNG/Diesel (Dual Fuel) trucks	CAT Dual Fuel	Refuse	Fueling station still in design phase.
Sacramento, City of	~50 LNG/Diesel (Dual Fuel) trucks	CAT Dual Fuel	Refuse	Fueling station still in design phase.
San Diego Refuse Collection (San Diego, CA)	54 Dual Fuel (LNG/Diesel)	Peterbilt 320 chassis, CAT Dual Fuel	Refuse	NexGen Fueling station with 15,000 gallons storage, 2 dispensers.
Santa Monica (Santa Monica, CA)	37 LNG buses on order (200 more planned)	NABI buses with Detroit Diesel Corp. Series 50G engines	Transit	Working to construct permanent LNG fueling station, completion 2002/2003.
Solano Garbage Co. (Fairfield, CA)	35 LNG refuse	Volvo trucks, Cummins 8.3G	Refuse	QRS (6,000 gallon skid-mounted tank)
Stater Brothers (CA)	20 LNG/Diesel (Dual Fuel)	International 9200 chassis with CAT C12 Dual Fuel	Line-Haul	
Sysco Foods (Los Angeles, CA & Houston, TX)	33 LNG/Diesel (Dual Fuel); 32 more on order	International 9100 and 9200 tractors, CAT C12 Dual Fuel	Line-Haul	Working to construct a permanent LNG fueling station with at least 15,000 gallons LNG, 2 dispensers
Taromina Industries (Anaheim, CA)	48 LNG/Diesel (Dual Fuel)	Refuse collection, transfer, and other trucks. Mostly Peterbilt chassis; all with CAT Dual Fuel engines	Refuse	QRS (6,000 gallon skid-mounted tank); also working to construct permanent 15,000 gallon LNG/LCNG station.
Tri-Met (Portland, OR)	1) 2 LNG 2) 8 LNG	1) Gillig, Cummins L10-240G 2) Flexible, Cummins L10-240G	Transit	

LNG Fleets

"Resource Guide for Heavy-Duty LNG Vehicles, Infrastructure, and Support Operations"

Fleet	Number of LNG Vehicles	Vehicle Information	Operation	Fuel Station Information
UPS (Ontario, CA)	1) 1 LNG (9 more on order) 2) 3 LNG	1) International truck chassis, CAT C12 Dual Fuel (Mack Trucks and engines) 2) Package cars	Delivery	16,000 gallon LNG fueling station built by Northstar
USA Waste (Waste Management)	13 LNG trucks	Volvo Expeditor, Cummins C8.3G	Refuse	16,000 gallon LNG fueling station built by Northstar.
USPS (Dallas, TX)	5 LNG		Delivery	
Valley Metro (Phoenix, AZ)	156 LNG; 96 LNG on order	NABI buses with Cummins C8.3G engines	Transit	South division station - 2-30,000 gallon bulk tanks, 3 pumps, 3 dispensers, up to 50 gpm; $1.4 million North division station - 2-30,000 gallon bulk tnaks, 3 pumps, 3 dispensers, up to 50 gpm
Vons/Safeway (Los Angeles, CA)	1) 30 LNG/Diesel (Dual Fuel) 2) 5 LNG yard tractors 3) 10-15 LNG tractors	1) Tractors with Cat C12 2) Yard tractors 3) Tractors with DDC S60G	Line-Haul	15,000 gallon LNG fueling station, 1 dispenser; built by Chart Industries.
Waste Management (Corona, CA)		Mack Trucks and engines	Refuse	16,000 gallon LNG fueling station built by Northstar.
Waste Management (El Cajon, CA)	120 LNG refuse	Mack Trucks and engines	Refuse	A 45,000 gallon on-site fueling station with three low profile storage tanks. The fueling facility at Waste Management has four fueling lanes.
Waste Management (Washington, PA)	7 LNG Refuse Haulers	1997, 1998, and 1999 Mack MR688S with Mack E7G-325 LNG Engines	Refuse	A permanent LNG fueling station equipped with an underground 13,000 gallon fuel storage tank. The facility can also convert liquefied to compressed natural gas (LCNG). LNG fueling station costs an estimated $700,000.

Significant input from Erik Neandross, Gladstein & Associates and George Kalet, NexGen Fueling.

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